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A combined technique approach for the study of a landslide in the Calabria region

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***Abstract* – In the detection and monitoring of a landslide a large number of variables should be taken into account. Several techniques and approaches should be used to fully understand the phenomenon in order to facilitate landslide stabilization design especially for complex cases. In this paper the case history of the Gimigliano landslide (Southern Italy) is investigated taking advantage of a combined-technique approach based on conventional geotechnical measurements used together with modern technologies such as electromagnetic sensing techniques and electrical resistivity tomography. The application of this methodology shows that combining the information taken from the different techniques is possible to validate the measurements obtained by conventional and modern approaches and enhance the accuracy of each other.**

I. INTRODUCTION

Landslides are highly complex phenomena because involve a very large number of variables. The most important factors which must be known in order to have a better understanding of the process are geometrical aspects and the their evolution in time, the geo-material parameters, the ground-water conditions. These variables are represented by surface and deep displacements, strength parameters, hydrological and hydrogeological characteristics and geometrical definition of the area of the landslide. Due to such a complexity, for carrying out a landslide characterization adequate to the slope stabilization planning, it is necessary to combine the standard geotechnical techniques with the innovative geophysical and/or electromagnetic sensing techniques. In this paper, a combined technique approach using the above mentioned techniques is applied for investigating the Gimigliano landslide in the Calabria region (Italy), with the aim to show how the combination of the different investigations drives to a better and more accurate understanding of the landslide phenomenon.

II. THE GIMIGLIANO LANDSLIDE

The town of Gimigliano (Southern Italy) (Fig. 1) is affected by the presence of several instability phenomena which are characterized by different types of landslides with different states, distributions and styles of activity because of the complex geological settings, as showed on PAI [1] landslide inventory map in Fig. 2.

Such instability phenomena have showed an intensification of activity in winter seasons 2009-2010 which caused damage to buildings and infrastructures resulting evacuation of few buildings and block of the practicability of some road.

The basic stratigraphic sequence presents phyllites, metarenites and metaconglomerates intercalated by metalimestones overlaying banks of metabasites alternated with serpentinites and ophicalcites that are part the Ophiolitic unit Monte Reventino.

In this paper the focus is on the investigations carried out to better define the phenomenon known as Gimigliano landslide involving a new building district and which is characterized by the presence of a detrital-colluvial deposit. This phenomenon shows a complex situation in which minor landslides overlap and in the central part cover the main body of the landslide (Fig.2).

III. FIELD TESTS AND MEASUREMENTS

A. Persistent Scatterer Interferometry (PS-InSAR™)

In this section the results of the Persistent Scatterer Interferometry are presented. The period of observation is quite long and is divided into two steps, 1993-2000 and 2002-2010. The results obtained from the data interpretation drive to interesting conclusions that allow to define a deformation scenario. All the data collected were interpreted through the PS-InSAR™ approach [2] and the satellite data used were taken from the ERS-1 and ERS-2 datasets for the period 1993-2000 and from the ENVISAT dataset for the period 2002-2010.

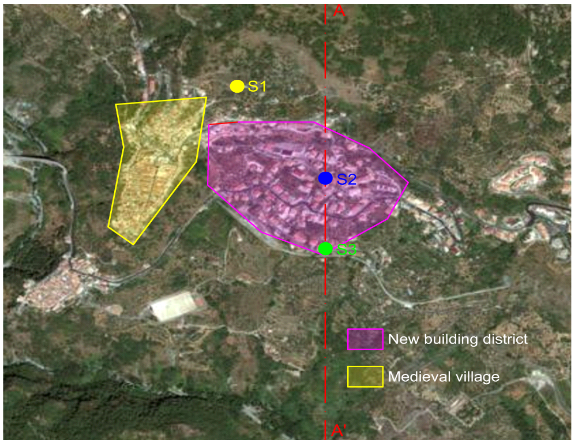

Fig. 1. Satellite view of Gimigliano and position of the boreholes.

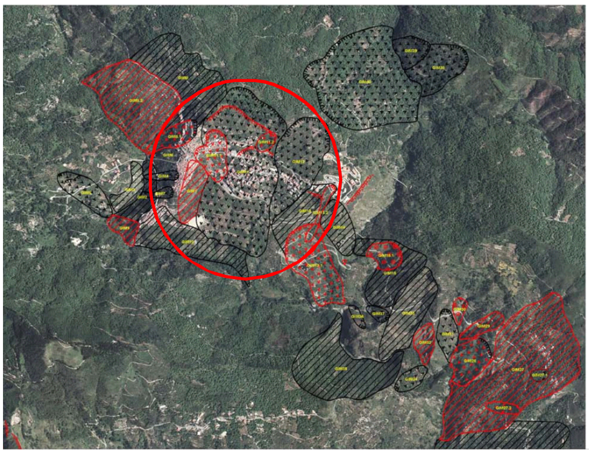

Fig. 2. PAI landslide inventory map.[1]

The main results of the analysis for the period 1993-2000 are showed in Fig. 3. The significant displacements in this period are located in the new building district of Gimigliano that is characterized by a subsidence rate that is higher than 2 cm/year (red dots). In the period 2002-2010 (Fig. 4) the scenario is different, the average displacements are smaller and there are two main areas interested by the movement, the new building district and the medieval village. In particular the new district is characterized by a subsidence rate of about 1.2 cm/year (orange dots), on the other hand is possible to point out that there is a migration of the deformation field to the medieval village that in this period is characterized by a subsidence rate that is small but not negligible of about 0.3 cm/year (yellow dots). Bianchini et al. [3] related to the 2010-2011 period give a confirmation of the trend showed from the 1993-2002 data using a TerraSar-X methodology. From the analysis of these new data it is possible to notice that the displacements are concentrated in the new district with a higher average velocity compared with 2002-2010 period, and that the medieval village is more stable with more or less the same velocity of the previous years.

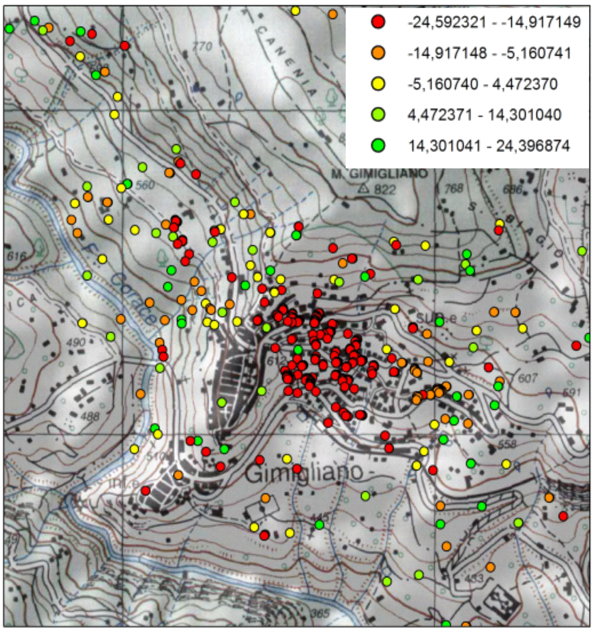

Fig. 3. map of the deformation (velocities in mm/year) for the ERS dataset 1993-2000 [2]

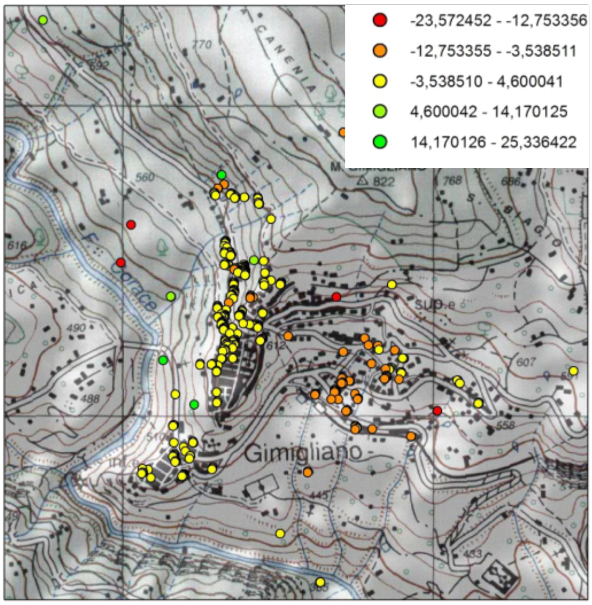

Fig. 4. map of the deformation (velocities in mm/year) for the ENVISAT dataset 2002-2010. [2]

The results obtained from this methodology have allowed to reconstruct the dynamic of the investigated area through the values of the mean yearly velocities since 1993 up to 2011.

From this analysis it can be pointed out that the landslide area is marked by a general deformation in evolution with acute and intense phases that alternate with more moderate phases.

B. Standard geotechnical techniques

After the paroxysmal phase occurred during the winter seasons 2009-2010 it was decided to improve the knowledge of the landslide through the execution of further and more detailed investigations in order to facilitate the risk mitigation design.

Regarding the standard geotechnical investigations taking advantage of the information derived from electromagnetic sensing techniques, three boreholes were drilled within the landslide main body. As showed in Fig. 1, the boreholes S2 and S3 are located in the new district area, previously marked by the highest velocity of displacement. The borehole S1 is located close the border between the medieval village and the new district corresponding to the crown of the landslide. The depth range of the boreholes varies between 70 and 76.5 m, and they were instrumented with inclinometers and piezometers.

The boreholes give important information about the stratigraphy of the area, analyzing them it is possible to confirm that are present phyllites, metabasites, serpentinites and ophiolitic rocks with different weathering grades.

Preliminary results from inclinometer measurements in the boreholes S2 and S3 indicate relative movements at depth of 58-60 m and 46-48m, respectively.

The lithology of the S2 borehole is reported in Fig. 5a from which it is clear that the displacements take place in the layer of very altered black phyllites (Fig. 5b).

Along the depth of the boreholes, ten pressuremeter tests were performed to better define the mechanical properties of the rocks. The results show a large variability of the parameters (pressuremeter elastic modulus and pressuremeter limit pressure) that is related not only to the change of stratigraphy but within the same material layer also to other factors such as the grade of alteration and weathering and the groundwater level.

C. Electrical resistivity tomography

Electrical resistivity tomography (ERT) is a geoelectrical method used to reconstruct the geometry of surface geological structures and to evaluate the electrical resistivity of outcropping geo-materials in order to determine their physical properties. Recently, the ERT method is also applied for investigating landslides, because the use of this method can provide important information upon the identification of the sliding surface, of groundwater effect, of internal structure of a landslide [4, 5]. For investigating the Gimigliano landslide, seven ERT high resolution surveys (one longitudinal and six transversal to the landslide body) were carried out, as indicated in Fig. 6, with lengths which vary from 235 m up to 940 m and reaching an investigation depth ranging from 35 m to 140 m and with 5-10-20 m electrode spacing in order to increase data coverage and quality.
The geoelectrical profiles, in which the topographic correction has been introduced, cover almost completely the landslide area. Particular attention was paid to the

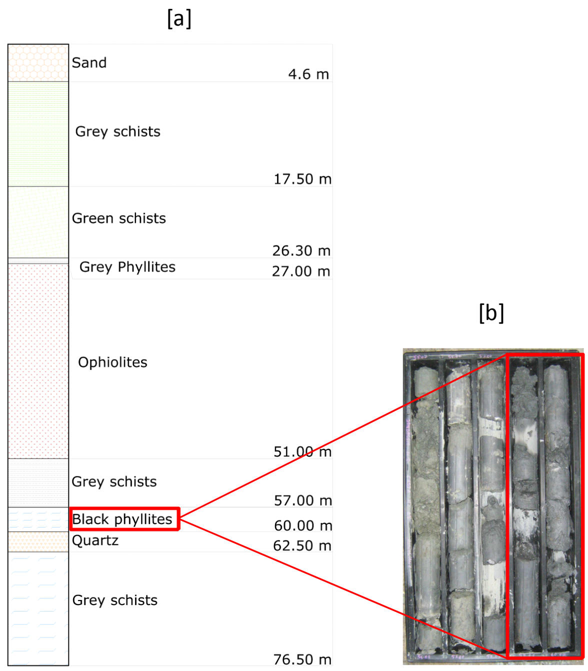

Fig. 5. Lithology of the S2 borehole [a] and picture of the black phyllites layer [b].

execution of the tests to take into account that the area is intensely urbanized. The Wenner-Schlumberger (WS) array configuration is used and the high-resolution geoelectrical tomographies are developed using the algorithm based on the smoothness-constrained least-squares inversion implemented by a quasi-Newton optimization procedure [6]. The tomographies show a chaotic distribution of the resistivity values with high variations in both horizontal and vertical direction. In some profiles, the resistivity values vary in the range 5-900 Ωm (Fig.6) [7].

With reference on the longitudinal profile (T4), that is almost parallel to the main landslide, it is possible to point out that there are weakness planes with very low values of resistivity.

IV. LANDSLIDE CHARACTERIZATION

All the results of the several techniques and measurements analyzed in this study, show a very complex and even chaotic geological setting. Even though this complexity make the definition of a landslide characterization very challenging, the combination of the above described techniques, allows to clearly define, at least, the kinematic aspects of the landslide. In Fig. 7 the A-A' section (almost coincident with the T4 longitudinal tomography profile) is showed. It is important to notice that the failure surface, drawn together with the stratigraphy derived from the S2, S3 boreholes, is located in the phyllites layer and that also the deep movements showed by the inclinometer

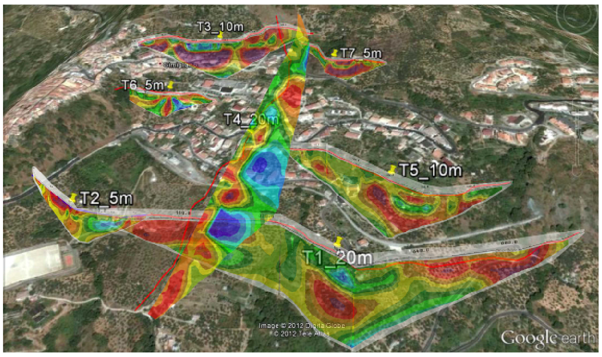

Fig. 6.Traces of the electrical resistivity tomographies.[7]

measurements are located in the same layer. Moreover, the information derived from the analysis of the electrical resistivity tomography, shows an accurate overview of the weakness plane that should be located within this layer.

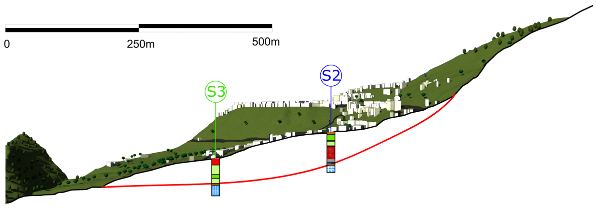

Fig. 7. A-A' section with the S2, S3 stratigraphy and the failure surface.

V. CONCLUSIONS

The complex Gimigliano landslide is investigated with a combined approach in which the geological and the geomorphological information and the standard geotechnical investigations are integrated with electromagnetic sensing techniques and electrical resistivity tomography.

The interferometric technique provides an accurate spatial distribution and a temporal evolution of ground displacements. The results show that, in the observation period 1993-2011, the landslide is marked by a dynamic with acute phases alternated with moderate phases. It is important to underline that this displacement field is confirmed by the first inclinometer measurements. These considerations should be verified through further measurements with updated data.

The geoelectrical methods, that are characterized by low costs and fast field investigations, provide useful information for the identification of the sliding surface, of groundwater effect, of internal structure of the landslide especially when calibrated with standard geotechnical investigations such as stratigraphic borehole data and inclinometer measurements. The tomographies show a very complex distribution of the resistivity values with high variations in both horizontal and vertical direction. This is confirmed and more clearly showed by the lithology derived from the boreholes and the values of the pressuremeter parameters. The examination of the lithology and the inclinometer measurements allows to conclude that the shear band is concentrated in the phyllites, combining this information with the ERT longitudinal profile (T4), it is possible to recognize the weakness plane for low resistivity value which is coincident with the above described phyllites layer.

All this shows that the combined approach can be considered a powerful tool for investigating landslide especially characterized by complex geological and stratigrafic settings.

ACKNOWLDEGEMENT

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