Integrated Surveying System for Landslide Monitoring, Valoria Landslide (Appennines of Modena, Italy)

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Key words: deformation measurement, engineering survey, GPS positioning, risk management

SUMMARY

The research object is the study and prevention of landslide risk through the utilization of integrated surveying systems like GPS and Automatic Total Station (Robotic station).

The measurements have been applied to Boschi di Valoria landslide, located on Appennines of Modena in the Northern Italy, which relatively large size, about 1.6 square km, required the use of both techniques. The system is made by Automatic Total Station, looking at 45 reflectors and a GPS master station, reference for three rovers on the landslide. In order to monitor "local" disturbing effects, a bi-dimensional clinometer has been applied on the pilaster where the total station is located. In a first periodically measurements were collected, while the system is now performing continuously. The system permitted to evaluate movements from few millimeter till some meters per day in most dangerous areas; the entity of the movements obliged to plan an alert system that was activated after a first phase of phenomenon study. Topographic measurements have been integrated with geotechnical sensors (inclinometers and piezometers) in a GIS for landslide risk management.

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INTRODUCTION

The research deals with the integration of surface displacement measurements obtained using geodetic and topographic instruments such as satellite GPS (*Global Positioning System*) system and traditional one, like automatic total station, in a large-scale active earth-slide. The case study is the Boschi di Valoria Landslide, located in the northern Appennines (Fig. 1) of Italy, which damaged roads and endangered houses during a sequence of reactivations in 2001, 2005 and 2007 (Ronchetti, 2007). The main risk is due to the position of the Dolo river. It is located at the toe of the slide and in case of event, the overflow of water could isolate entire small villages. In addition to that, the possible retrogression of the rear scarps could cause relevant damage to infrastructure.

The Boschi di Valoria Landslide, also known as the Valoria Landslide, is an ancient landslide (Manzi, 2004) that has displayed multiple reactivation phases in the last 60 years and actually has a high potential for further development, both in the upper landslide zone and in the toe area (Borgatti, 2006). The analysis of its movements is important because it is not known the way of evolution of the complex slide and for this reason it is not possible to create a prevention model. So that, the system architecture is composed by both topographic and geotechinical instrumentation. The actual configuration of instrumentation is related to years of studies in the recent past and to an accurate experimentation that caused also the loss of instruments. Topographic measurements have been integrated with geotechnical sensors (inclinometers and piezometers) in a GIS for landslide risk management.

The surface monitoring of the landslide needs both GPS and robotic station systems because of its relatively large size (about 1.6 kmq: 3.5 km long and 0.7 km wide - Fig.1-).

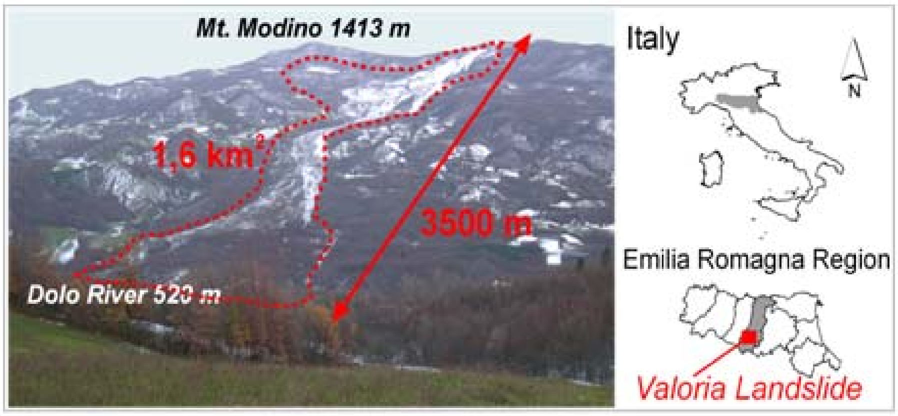


Fig. 1: Location map and panoramic view of the Valoria landslide in February 2006

1. Geological FRAME

The Valoria landslide affects Cretaceous to Miocene rock masses such as sandstone dominated flysch, and silty to clayey shales (Fig. 2).

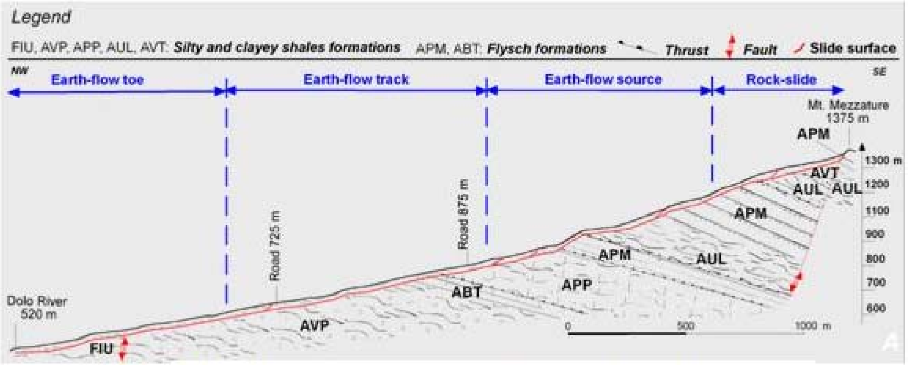


Fig. 2: Cross section of the Valoria landslide

In the slope, these rocks are deformed by overthrusts and faults. The landslide deposits can be described as blocks in a silty-clay matrix. The Valoria landslide can be subdivided into different zones. The upper rock-sliding area extends between 1375 and 1200 m. Roto-translational movements involve clayey and flysch rock masses outcropping in the crown. The earth-flow source area is located between 1200 and 925 m, where the displaced rock masses are completely dismembered and then incorporated into earth-flows. The earth-flow track extends from 925 to 650 m. The landslide toe is located between 650 and 520 m. Drill-holes and refraction seismics have shown that the thickness of rock masses involved in slides at the landslide crown is between 5 and 40 m, and that the thickness of earth-flow deposits along the slope varies from a few meters in high slope-gradient regions to more than 30 m in low slope-gradient regions of the track and toe areas, where deposits of different age are accumulated.

An age of about 7800-7580 cal yr BP was obtained for a wood fragment collected close to the bedrock interface in the landslide toe zone.

2. LANDSLIDE Monitoring

Monitoring has been initially performed by means of an automatic total station measuring about 45 prisms located to a maximum distance of 1.650 km, double-frequency GPS receivers for periodic fast static acquisitions in 11 benchmarks. Until December 2007 the monitoring network was operated with periodic fast static surveying followed by the data post-processing. The robotic station and the GPS master station have been located in a relatively stable geological area, called Aree Vecchie.

Fig. 3: *Master unit composed by GPS (left) and robotic station (right)*

Since March 2008 the total station system was automated in order to allow continuous data acquisition and near-real-time data processing and since July 2008 also a GPS continuous network is operating.
Actually the master unit (Fig.3) consists of a robotic station (*TCA2003 Leica)* and of a double frequency GPS receiver (*GMX902 Leica)* with an antenna *AX1202 Leica.*

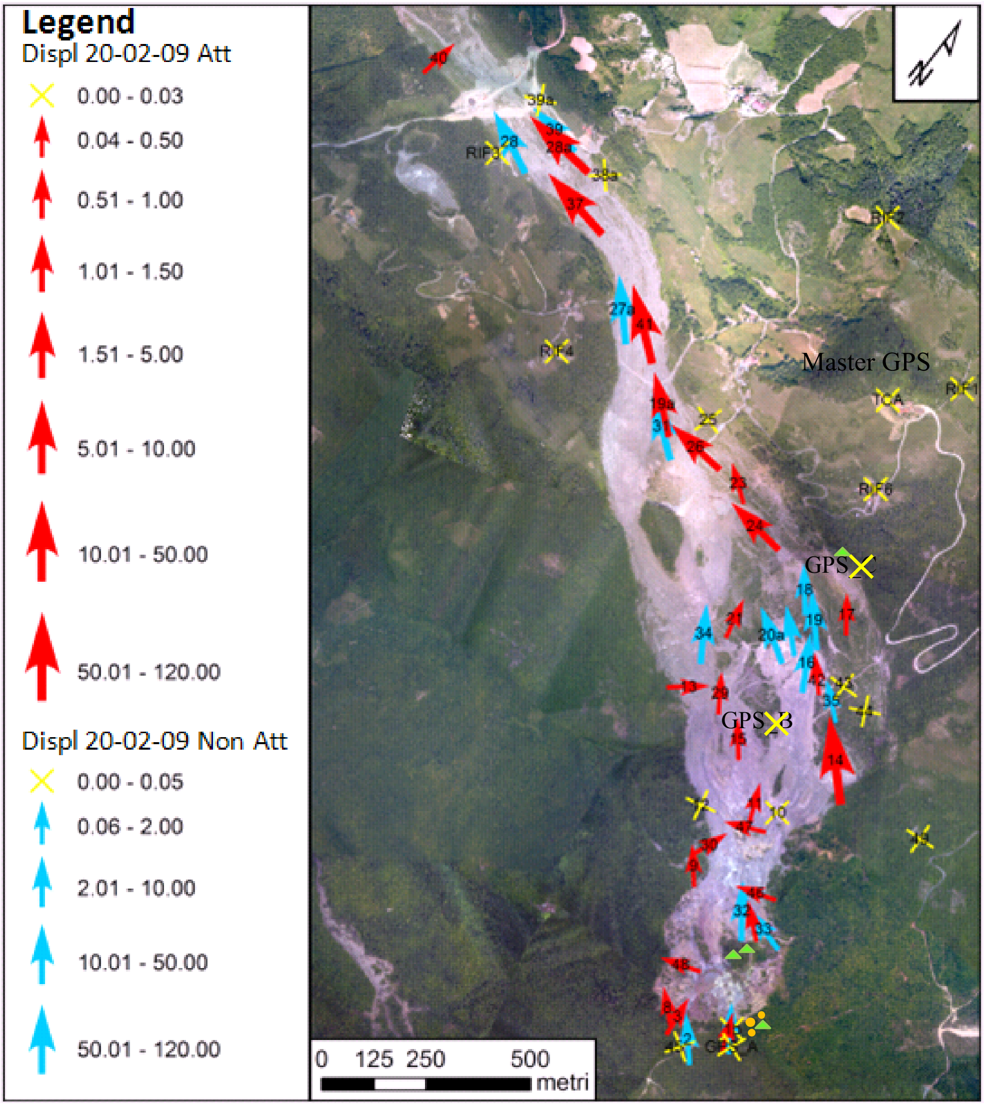


Fig. 4: Localization of topographic and geotechnical instruments on Valoria Landslide. Continuous system architecture. Movement vectors of prisms and GPS on the landslide: blue arrows - displacements of lost prisms and red arrows – displacements of active reflectors. Rif1, Rif2, Rif3, Rif4, Rif5, Rif6 are reference reflectors. GPS_A, GPS_B, GPS_C are rovers GPS. Extensometers are indicated with a orange circle and borehole instruments (piezometers and inclinometers) with a green triangle.

The master GPS, now a permanent station continuously tracking satellites, has been adjusted in the ETRF89 reference frame by means of three permanent stations making part of the Assogeo network. In order to monitor "local" disturbing effects, a bi-dimensional clinometer (*Nivel 220 Leica)* has been applied on the pilaster where the total station is located, and it is working from July 2008. Instruments are powered by electric current, but in case of outage there's a service battery able to supply power for 2 hours. The antenna is mounted with a special adapter on the top of an aluminium empty pole fixed 2 m in the soil and filled with the same terrain. The robotic station works covered by a special case on a reinforced concrete pole 1.60 m high. The glass of the box would provoke a distortion in the measure which is lower than the measurement accuracy, therefore it can be ignored; in addition to that we can state that even if it is significant it could be neglected, compared to landslide movements. The two station's pole have been connected by a reinforced concrete basis. Measures are collected on a remote controlled computer.

The monitoring network has been able to cope with displacement rates ranging from millimeters to meters per day, a performance not achieved by borehole systems operated in the slope, such as in-place inclinometers, that were damaged when displacements exceeded some decimeters.

The data so far collected, integrated with geomorphic, geologic and borehole data, allowed the complex spatial and temporal pattern of slope movements to be tracked and the relationships between rainfall pattern and acceleration-deceleration phases to be highlighted. Master unit, instruments and reflectors positions are shown in the Fig. 4.

Fig. 5: *Example of GPS benchmark – periodic survey*

Periodic surveys

Periodic surveys have been set as follows:

- three periodic GPS campaigns from November 2007 until January 2008 were made every two weeks. Fast static surveys of about 20 minutes with a logging rate of 1 second and a double frequency receiver on the 11 GPS points (Fig.5) on the landslide, detected displacements as shown in Tab. 1 and Fig. 7;

- seven periodic surveys with the automatic total station TCA2003 from December 2007 to February 2008 every two weeks. The robotic station measured about 45 reflectors with a special mount (Fig. 6); 39 are in the body of the landslide, installed on a reinforced rod fixed in the soil for 1.5-2 m; 6 are used as reference and are positioned out of the landslide on electric pylons, houses, etc. (Fig. 6 (c)). All reflectors have been named with a number in order to recognize them after great movements. Only most significant displacements have been shown on graphics for the north - Fig. 8 (a) -, east - Fig. 8 (b)- and upper - Fig. 8 (c) - direction. Coordinates are referred to the total station which is the center of the local reference system.

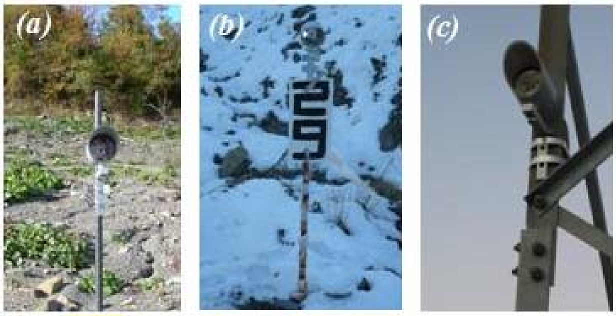
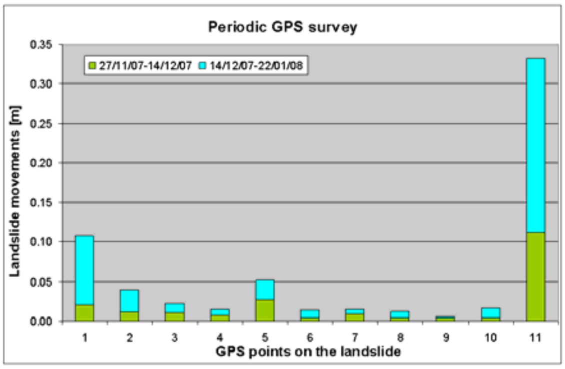


Fig. 6: *Reflectors with special mount*

Landslide movements: |Δ| in [m]		
GPS point ID	*27/11/2007-14/12/2007*	*14/12/2007-22/01/2008*
1	0.0200	0.0873
2	0.0106	0.0284
3	0.0100	0.0117
4	0.0076	0.0071
5	0.0270	0.0241
6	0.0041	0.0095
7	0.0095	0.0054
8	0.0036	0.0082
9	0.0036	0.0020
10	0.0040	0.0122
11	0.1123	0.2206



Tab. 1 and Fig. 7: Landslide displacements detected with GPS periodic surveys

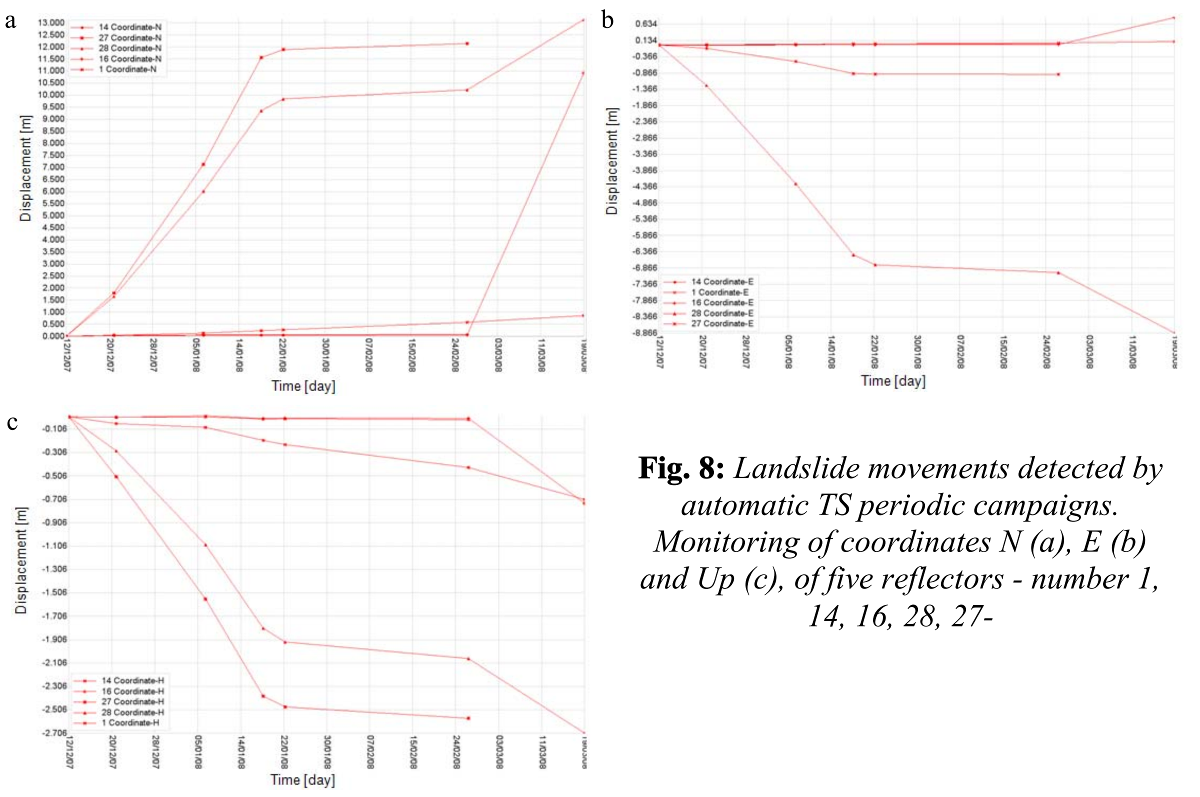


Fig. 8: *Landslide movements detected by automatic TS periodic campaigns. Monitoring of coordinates N (a), E (b) and Up (c), of five reflectors - number 1, 14, 16, 28, 27-*

Continuous measurements

The system architecture for continuous measurements is quite similar to the periodic one (November 2007 – March 2008) and derives from its analysis and results (Capra, 2008).
The robotic station measures about 45 reflectors every three hours. Some of them have been lost during the summer. In the most "hot" area, some of them have been replaced and renamed, but others are lost definitively. Landslide movements by automatic TS most significant reflectors during continuous measurements are shown in Fig. 9.
The GPS network is composed by the master GPS, located at Aree Vecchie, which is the reference station for three single frequency GPS rovers, located in the landslide (Fig. 10) (*GMX 901 Leica)*. Data are transmitted by wireless system to the master unit where the GNSS Spider software creates hourly and daily rinex files. The installation is the same both for master and rovers: there is a pole fixed in the terrain for 1.5-2 m and filled by the same soil with a special adaptor on the top. Power supply in rovers installation is from photovoltaic panels.
Some areas registered massive movements of terrain and prisms moved with velocity up to m/day. Fig.9 and Fig. 11 report displacements for points with great movements. But, at the same time, even low velocity could be interesting if the point are located in area where a movement is not supposed in advance.

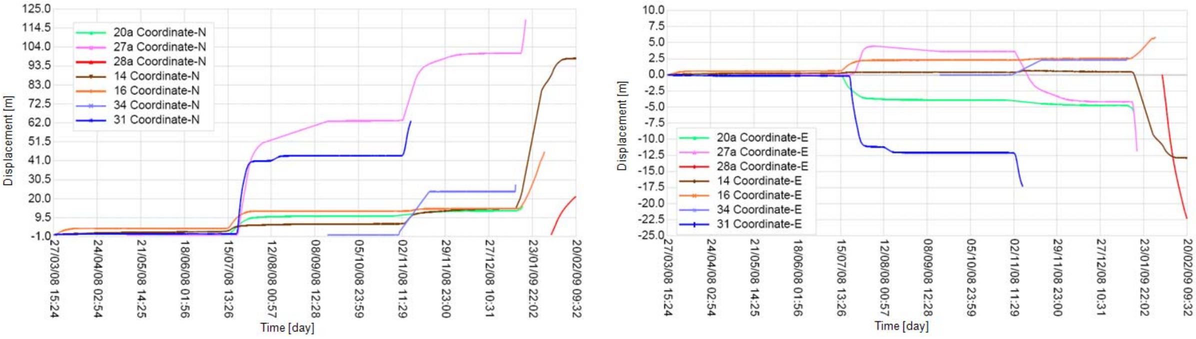


Fig. 9: Landslide movements by automatic TS during continuous measurements. Monitoring of coordinates N (left), E (right) of the most interesting reflectors.

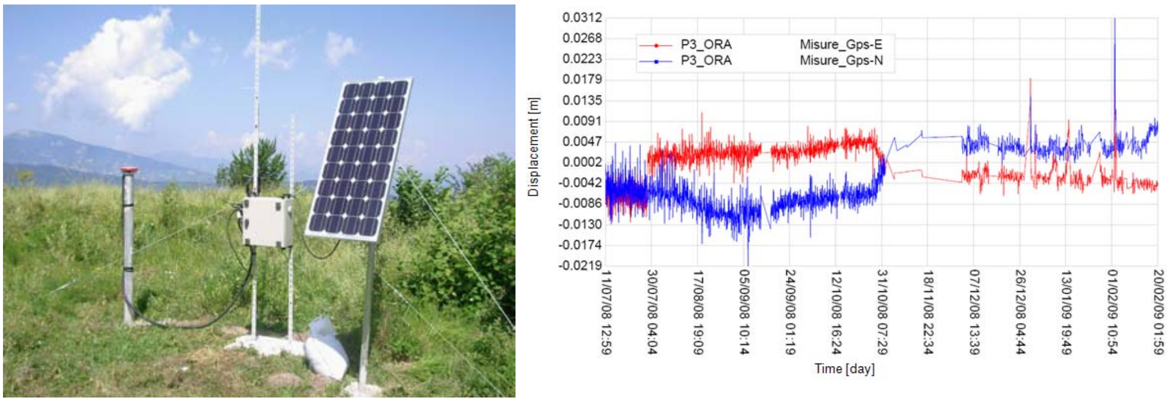


Fig.11:GPS rover (left) and its displacements in N,E coordinates (right)

Therefore it is urgent to establish an automatic procedure for data analysis and threshold of risk in order to activate an alert system.

The system is actually in a testing phase, and it is not completely automated. It needs an operator for data interpretation. But the purpose is to create a completely automated system remote controlled able to give warnings in case of event.

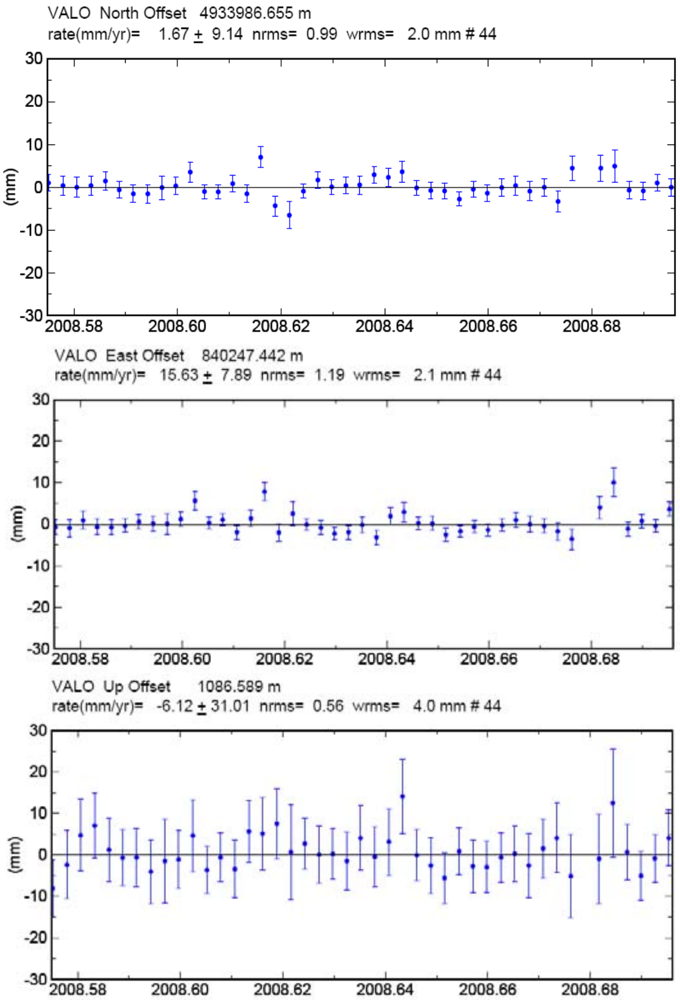


Fig. 10: Master GPS's temporal series: from the top, North. East and Up

3. STABILITY OF MASTER STATION

The master unit of the system is located in a relatively geologically stable area. From past studies of Valoria Landslide and contiguous areas, Aree Vecchie seemed to be enough stable.

In order to monitor "local" disturbing effects, a bi-dimensional clinometer have been applied on the pilaster where the total station is located. Its data are compared with these of the total station sensor which measures the verticality of the instrument (machine's tilt). From summer continuous measurements of these sensors appears a movement of the area. Fig. 12 (left) shows how the robotic station moved until the end of June, when was riverticalized, and how, in accordance with the clinometers (Fig. 12 -right), kept the trend for the following period.

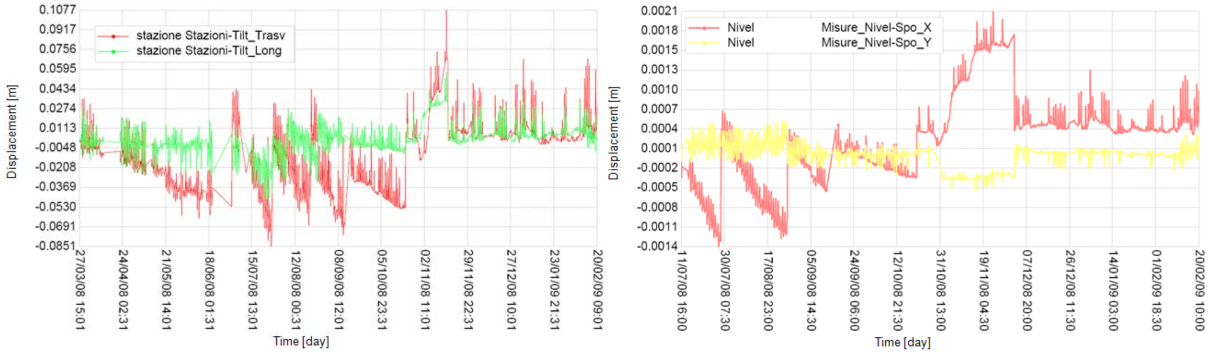


Fig.12: *Tilt of robotic station (left) and measurements of bi-dimensional clinometer (right)*

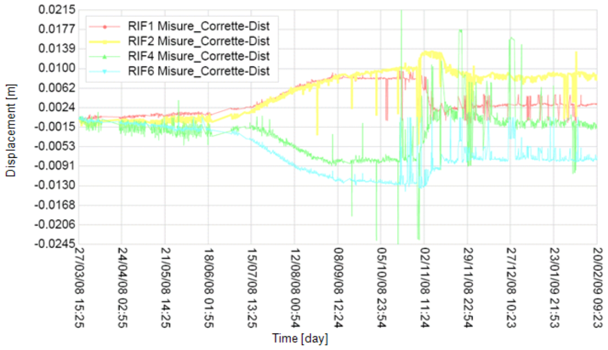


Fig. 13: *Variation in time of the distance from the robotic station and reference reflectors*

For this reason both TCA2003 and Nivel have been riverticalized many time during the summer, in order to have their perfect functionality. TCA2003 works in a range of 0.08 gon while the Nivel, in a range of 0.0012 rad. Movements of the area, now stopped, are probably due both to installation settlements and to soil retreat caused by the dry season. The behavior of the master area is confirmed by reference reflectors; they seems to move away from the total station (Fig. 13). The confirmation of the master unit saesonal movement theory could be given by the master GPS data analysis. GPS data of the master permanent station, VALO, were archived and then processed in daily sessions with respect to the EUREF permanent station, MOPS, located about at 50 km far away (fig. 11). At the paper writing time, it is not possible to say nothing about VALO stability because it is working just from few months, exactly from the 28th July 2008. In the near future, GPS data are going to be deeply studied and analysed so that it could be possible to find out an explanation to the area movement and compute the displacement velocity, if it will be significant in the eyes of this study. This value will be useful to make all the measurements already done independent from the area movement: to be more precise, the master displacement component has to be removed and must not be wrongly read as a displacement of generic prisms on the landslide.
A further analysis, with the purpose of giving an answer to the stability doubts, was VALO data post-processing in daily sessions by means of *Gamit/Globk* software (Fig. 13). GPS data archive computed was 1.5 months long. VALO coordinates were computed and adjusted in the IGS05 reference frame with respect to the nearest EUREF permanent stations and by means of their published coordinates (MOPS, MEDI, PRAT, IENG, MESL).

Geotechnical & Hydrological instrumentation

Monitoring data have been collected inside and outside the landslide with sensors and loggers recording on a semi-continuous basis: rainfall, air temperature, groundwater flow and displacement rates (with wire extensometers, inclinometers).

4. CONCLUSIONS AND FUTURE DEVELOPMENTS

Thanks to the integrated system applied to Valoria landslide it has been possible to observe a big landslide in each part of it, even part of the landslide that are not accessible at all.

Integrated monitoring system is now at work, even if not completely automated. An operator downloads and analyses data collected, remotely. It's his task the evaluation of the risk and to put in state of the alert authorities and then the Civil protection. The objective for the next future is that of create a completely automated procedure for data analysis and management.
Most significant displacements, measured by periodic surveys, took place during autumn 2007. During 2008 movement entity was less important than that of 2007, especially during spring and summer time, it should be related to drier climate in last year. In any case the displacements were significant in comparison with these of the master unit and therefore not unimportant.
The stability of station pilaster used for Robotic instrument was controlled. Till now, master GPS data elaborated do not confirm this trend, but more measurements must be analysed in order to establish if consider this movement or not and therefore correcting elaborations. The measurements indicated that the master area seems to show a cyclic movement; Total station pilaster's displacement seems that should be done to a differential movement of reinforced concrete basis of master unit monumentation, maybe because of the different construction phases or due to not homogeneous terrain substrate (not investigated with appropriate probing). Reference reflectors movements confirm the summer sinking of total station's pilaster maybe caused by the material retreat. In fact, the movement stopped with autumn. The cyclic movement of master station seems to be perfectly elastic, so it should not disturb data analysis and results interpretation.

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BIOGRAPHICAL NOTES

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Andrea Capitani, born in Modena (Italy) on 17-07-1982. In December 2008 he got a Second level degree in Environmental Engineering at the University of Modena and Reggio Emilia. Title of the Thesis: "Sistema di monitoraggio integrato della frana di Boschi di Valoria (Frassinoro (MO), Italy)". He has duties in monitoring systems and their applications to landslides.
Alessandro Capra was born the 5/5/1961 in Bologna. University degree in Mining Engineering. Full Professor of Surveying and Mapping at Engineering Faculty in Modena of Modena and Reggio Emilia University. Chief officer of Geosciences group of SCAR (Scientific Committee on Antarctic Research). President of SIFET (Italian Society of Photogrammetry and Surveying) scientific committee. Editor-in.-chief of Applied Geomatics journal.
Cristina Castagnetti, born in Reggio Emilia (Italy) the 22 July 1982. October 2006 second level degree in Environmental Engineering with first class honours at Modena University. At the moment, Ph.D. student at the High Mechanics and Automotive Design&Technology School, University of Modena (Engineering Faculty). Geomatic is the main topic and in detail GNSS systems applied to navigation. Scientifical publications: 2.
Alessandro Corsini was born the 25/5/1971 in Modena. University degree and PhD in Geology. Senior Researcher of Engineering Geology at Engineering Faculty in Modena of Modena and Reggio Emilia University. Active Member of CERG (European Centre of Geomorphological Risks). Author of more than 50 publications.
Marco Dubbini. Born in Ravenna (Italy) the 02 May 1967. Degree in Civil Engineering at University of Bologna in 1998. Ph.D. in Geodetic and Topographical Sciences at University of Bologna in 2002. At the moment Scientifical Technical Graduated employment at University of Bologna. Num. 23 scientifical publications.
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