THE SECOND WORLD LANDSLIDE FORUM

**Stefano Cardellini , Paolo Osimani**

# The Ancona early warning centre, instrumentation and continuous monitoring of the landslides

**Ancona monitoring centre, Ancona municipality, Largo XXIV Maggio 1, +39 0712221**

**Abstract**

The "Grande frana di Ancona" is a deep-seated landslide inside the city area, reactivated in 1982 after a long period of precipitation. In 2009 Ancona Administration, with a law specifically issued for the people living there, creates an Early Warning System and Emergency Plan; it was developed a surface monitoring system integrated by a subsurface in place geotechnical system

- **Surface Monitoring system**

The combination of different instruments: GPS, Automatic Robotic Stations and tiltmeters sensors allows to monitor a great number of points previously identified.

- **Geotechnical monitoring System DMS**

In place Geotechnical Monitoring System DMS (patents and trademark CSG-Italy) was installed in February 2009 and is made by n°3 Modular Dynamic System

- **Early Warning Management**

In Ancona Early Warning Centre a staff controls the monitoring data and alerts the Coordinator in case of emergency.

**Keywords** complex composite landslide, early warning system, risk management

## Introduction

On 13th December 1982 Ancona city, historical and capital region of Le Marche - Italy, located on the East coast of the Adriatic Sea, was involved in a large and deep landslide. (Fig 1).

Figure 1 : Italy and Ancona city

An intense landslide, involving a volume of about 180 millions of cubic meters, affected the northern area of the city, the "Montagnolo" which started to slide towards the sea (Fig 2)


Figure 2 : Area affected by the landslide in 1982

Structures, infrastructures and some important public and strategic buildings, among them the Faculty of Medicine building, the Oncological Hospital, the Geriatric Hospital and the Tambroni retirement home were damaged. All the older people and the patients were moved to the nearest Hospitals for the first aid.

The National Railway MI-LE (Adriatica) and regional Highway Flaminia slid down 10 metres towards the sea. The movements started from the lower border of the landslide and came up the slope. At the end of the event the surveyed displacements were: 8 metres in horizontal at the base and 3 meters on height, while on the top 5 meters in horizontal and 2,5 meters downwards.

On the 13th of December morning, after a night of uninterrupted movements and noises due to the opening fractures of buildings, the Residential Districts named "Posatora" and "Borghetto", were evacuated. (Fig 3)

The landslide damaged private houses and infrastructures and about 3000 people were evacuated.

Municipality moved 1582 people to hotels and other residences and they remained in that situation for a long time.

Figure 3 : The regional Highway Flaminia 1982

Gas and water supplies were interrupted too and the city remained for some days without the necessary services.

The more significant damages can be resumed as following:

- 220 hectares extension (affecting 11% urban area of Ancona)
- 3661 people evacuated (1071 families)
- 1562 people moved to hotels and other residences by Municipality
- 280 buildings destroyed or damaged (a total of 865 residences)
- Faculty of Medicine building, Oncological Hospital, Geriatric Hospital, Tambroni retirement home, were irreparably damaged
- 31 farms damaged
- 101 SME (small and medium enterprises)
- 3 industries
- 42 shops
- 500 people lost their jobs
- National Railway MI-LE (Adriatica) and regional Highway Flaminia blocked
- Gas and water supplies interrupted
- Luckily, no people died during the event!

The dynamic of the Landslide of Ancona can be explained in two steps:

1. A gravity settlement happened at high depth probably induced by some dislocations activated during the 1972 earthquake, then re-activated by the intense rain infiltration (some days before the event it rained for almost 6 days without any interruption).
2. After the first step we had an activation of superficial and medium landslides. These started to move after about 10 minutes, with consequent damages to buildings and infrastructures (this second step continued for some hours)

The superficial geomorphology of the Ancona landslide is influenced by many and complex movements. The colluvial soils, in some places of the flanks, where their thickness is about 10 meters, have flown down as a mudslide. This dynamics was helped by the high rate of saturation.

Taking into account all the researches and both in-situ and laboratory investigations during the last 25 years, we can conclude that the Great Landslide of Ancona city is an Deep-seated landslide (complex, composite according to Cruden & Varnes 1996) reactivated after a long period of precipitation; new fractures were opened by a long period of earthquakes 10 years before (6 months duration) (Fig 4).

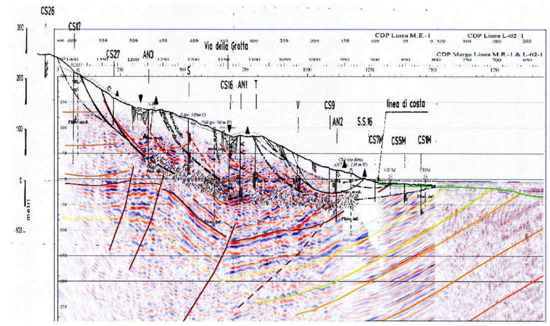


Figure 4 : Geomorphological and seismic section

The landslide involves clay and silty clay layers (Pliocene-Pleistocene) fractured with different OCR parameter, alternated with thin sand levels.

Overlapped sliding zones are active (maximum depth: 100-120 m, maximum depth 1982 event is 75 m bgl).

Across all the body of the landslide, in horizontal direction, parallel to the coast, there are two natural trenches that cross the slope. These trenches are upstream of old landslides slid down and now they are filled with heterogenic and plastic soils. These soils involve clay and silty clay, mud and thin sand level with some fragments of calcarenitic layers.

These trenches together with a complex structural system of fracture and discontinuity influenced the system of underground water.

All the geological and geotechnical analyses of the landslide mechanisms aimed at the preliminary consolidation design in the 2000; but the consolidation was unrealizable because of the high cost of the works and the environment effects; the works also would have changed the structure of the area with a deep socio-economical impact.

Ancona Administration decided then to live with the landslide reducing nevertheless the risk for the people living there.

Over the years, some partial interventions of the total preliminary design, for the consolidation stroke, have been made. Two drainage systems were done, one deep based on trenches and wells, and a more superficial one with canals. Reinforced bulkheads were built and in some part of the area reforestation was made.

Ancona Administration decided to continue the drainage systems both superficial and deep.

In 2002 the Regione Marche, (one of the main administrative units in Italy) made a special law for the people that still live on the landslide area, in order to give Ancona Administration the responsibility of creating an Early Warning System and an Emergency Plan. The goal of the project is to control the safety of the population by a continuous monitoring plan of the landslide displacements.

The projected Early Warning System consists of an integrated and continuous monitoring system aimed at the control at both superficial and deep displacements over the whole area (Fig 5).

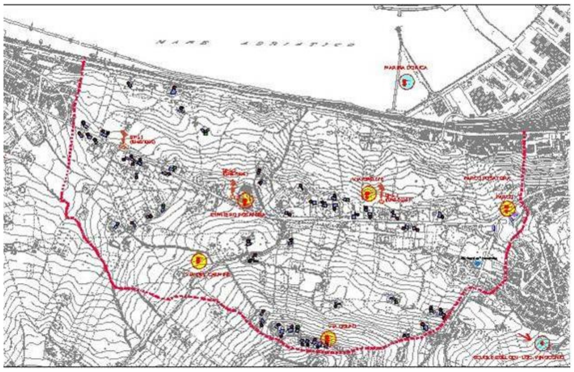

Figure 5: Map of the instrumented sites

## Surface monitoring

The surface monitoring system is based on:

- 8 Automatic Robotic Stations (of high precision)
- 230 reflector points (installed partly on the 64 inhabited houses and on the structures and infrastructures)
- 26 geodetic GPS (Global Position System) at single frequency L1 (installed on the 64 inhabited houses)
- 8 geodetic GPS at dual frequency L1+L2 (reference)
- 8 high precision tiltmeters sensors for the stability control of the main stations of the I and II level of the net (automatic geodetic boxes).

The combination of the different instruments: GPS, Automatic Robotic Stations and the inclinometric sensors allows a 3D monitoring of a great number of points previously identified. The adoption of the geodetic GPS at dual frequency assures a high quality of the GPS measures, and a greater versatility at all the system.

The monitoring system was designed to detect every surface movement by sensors installed both in the area and on inhabited houses. A staff of technicians, in the 24Hour Control Centre placed in the Town Hall, manages the system and evaluates the alarms to be forwarded to the Civil Protection.

The measuring cycle is set up on 30 minutes, but in emergency or after a long rainy period, the system can operate on every points of the dual frequency GPS net also in Real Time RTK, and with the 8 Automatic Robotic Stations (Fig 6).

Figure 6: The integrated monitoring station"Grotte"

The surface monitoring is based on GPS system in 3 different active levels, on 8 Automatic Robotic Stations and a later control with 8 high precision inclinometric sensors for the stability control of the main stations of the I and II level of the net:

**A - GPS system:**

1. Main Network (I level active at the moment) formed by 3 main stations outside of the landslide area with 3 geodetic GPS at dual frequency L1+L2 (reference) placed on two steady buildings (University and Collodi school), and a third one placed on a Geodetic box at Marina Dorica founded with a reinforced concrete pole (18 m).
2. Secondary Network (II level active at the moment), formed by 5 main stations inside the landslide area with 5 geodetic GPS at dual frequency L1+L2 (reference) placed on one building and on 4 Geodetic boxes founded with reinforced concrete poles (12-18 m).

All these geodetic GPS (no.3 + no.5) form a high precision net working in the Early-warning system, on different control levels, to assure the GPS net (at single frequency L1), installed on 26 inhabited houses, a strong network; so that after an alarm it can work in real time RTK.

3. Third Network (III level active at the moment) formed by n°26 geodetic GPS at single frequency L1 installed on 26 inhabited houses inside of the landslide area.

**B - Automatic Robotic Stations**

Eight high precision Automatic Robotic Stations are placed in the I and II level networks, in the same places of the geodetic GPS at dual frequency L1+L2, except for the "Collodi school" building. They control (angles and distances) of 230 reflector spots placed on the inhabited buildings left and on the consolidation structures built inside the landslide.

## Geotechnical monitoring (DMS)

In February 2009 an in place Geotechnical Monitoring System DMS (patents and trademarks CSG-Italy) was installed. The system is composed of n°3 Modular

Dynamic System columns installed in 3 boreholes (100 metres depth).

DMS columns are composed by modules containing the sensors, allowing in this way a continuous multiparametric measurement of the parameters for the whole length of the column. Modules are made of stainless steel, which makes DMS columns very robust and able to reach high depth, sensors are strictly tested to ensure a high level of accuracy. The modules are linked by special 2D/3D flexible joints that allow strong, continuous adaptability to bends and twists of the borehole, whilst maintaining rigorously the orientation with respect to a reference system defined during installation. Moreover DMS columns can be preassembled in lab and after installation in site can be repositioned extending or reducing the monitored depth; this activity can be done easily also on site.

Each column installed in Ancona is composed by 85 Biaxial Inclinometric modules (range +/-20°, resolution 0,01°), 2 Piezometric Sensors (range 100 psi, resolution 0,01 m) and 85 Temperature Sensors (range 0-70°C, resolution 0,1°C). The total active length is 85 metres (the first ten metres and the last five ones are without any instruments) with 173 transducers connected each other. Digital compasses are also on board.

#### DMS Early warning management

The control unit receives data from the DMS column by RS485 protocol; it compares them with threshold values (set by the user) and stores them in a circular buffer (Fig 7).

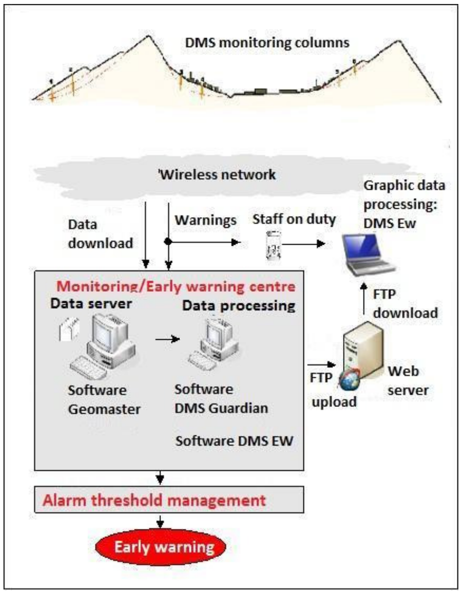


Figure 7: DMS Early Warning system

In case of displacement values higher than the threshold values, the control unit sends a warning SMS/direct call to the staff on duty of the monitoring centre.

The same is for rapid changes of water-table level. Warning levels are counted from 1 to 4, in a growing order of danger.

In the monitoring centre, the management software GeoMaster takes care of downloading the data stored in the control unit memory buffer.

DMS Early Warning is the software that visualizes the subsurface data at the monitoring centre and wherever an Internet connection is possible. The software, in a compact check panel, allows the contextual control of displacement (E-W, N-S, Module diagrams, on Polar and Azimuthal plots) as well as the variations of the level of the water table and temperature; time history of each multiparametric module and displacement-velocity are also displayed at selected intervals.

### Transmission System

The transmitted data coming from the different sensors are collected according to the two following procedures:

I and II Level Net: data transmission in real time through a Wi-Fi Standard HyperLan to the Town Monitoring Centre. The system is based on a main radio line (spot to spot) between the Automatic Robotic Stations and the Ancona Municipality Monitoring Centre. Data transmission in real time works through some free frequencies radio links of 5,4 GHz (HyperLan).

III Level Net: data transmission through periodic GSM in "dialling" with a data acquisition every 6 hours.

DMS data transmission is by GSM–GPRS.

### Early warning evacuation protocol

In order to increase the efficiency of the Civil Protection and guarantee the population safety an organization with the scope to follow and manage the evacuation protocol was developed.

The mayor of Ancona is the chief and has the responsibility of communicating both with the manager of Public works and the Civil Protection. The data collected by the monitoring systems are evaluated by two technical managers, one for the surface monitoring and one for the geotechnical monitoring, and by a representative for the civil protection.

With the aim of managing the situation of potential risk for the population an Evacuation Protocol was developed. In case of receiving an alarm the procedure must be followed step by step and, if the alarm is confirmed, must end with the activation of sirens. In case of activation of sirens the population must get out from their houses and follow the instruction of the Local Civil Protection Plan.

In the monitoring centre, technicians have the task to analyze data from instrumentations; the protocol includes a table of values used to evaluate the warning level in real time. The markers used are:
Signals (cracks or subsidence); Rain; GPS; TCA; NIVEL; DMS.

Once the alarms from the markers are validated, they are compared with the table which indicates the stages of activation warnings (attention, early alert, alert, early warning, and warning) and the resulting actions.

## Monitoring data on rainfall event of March 2011

Being continuous monitoring instruments, DMS system are able to collect data in real time, thanks to this system it is possible to compare different data between them. In order to understand how rainfall, water table and displacements are linked, an analysis on the delay time between them was performed.

Analyzing rainfall events occurred in Ancona and data from DMS system the delay time between the rainfall events, the raising of water table level and the beginning of micromovements were calculated.

The 3 largest rainfall events occurred in Ancona since 2008:

1. From 27/02/2011 at 17:00 to 03/03/2011 at 6:00 with a cumulative rainfall of 161,8 mm
2. From 27/09/2010 at 15:00 to 01/10/2011 at 9:00 with a cumulative rainfall of 134,1 mm
3. From 03/03/2008 at 10:00 to 08/03/2008 at 16:00 with a cumulative rainfall of 109,2 mm

For the analysis the first event, happened in 2011 was chosen (Fig 8).

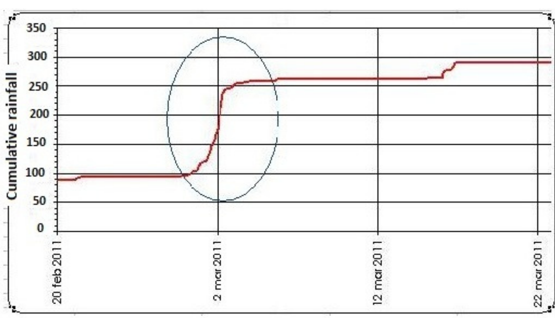


Figure 8: Cumulative rainfall in March 2011

On each of the three columns the delay time between the event and the raising of the water table was calculated, and it was evaluated if there were displacements soon after the events.

For the first column, called DMS Ancona1, the water level starts to rise on the 27th of February at 23:00, 30 hours after the start of the pluviometric event (Fig 9).

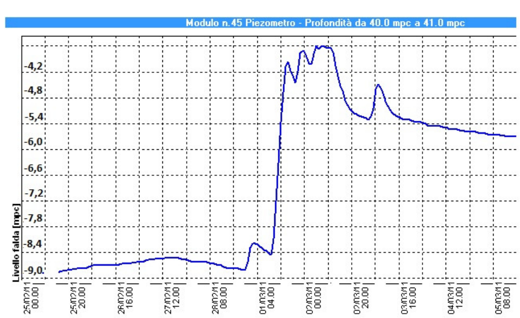


Figure 9: Water table level on DMS_Ancona1 site

By aligning the column at the 27th of February, starting date of the event, it was possible to notice some micromovements (Figure 10):

- On module 18, depth 67-68 m, from 29/03/11 to 05/04/11, (blue line)
- On module 22, depth 63-64 m, from 05/04/11 to 09/04/11, (red line)

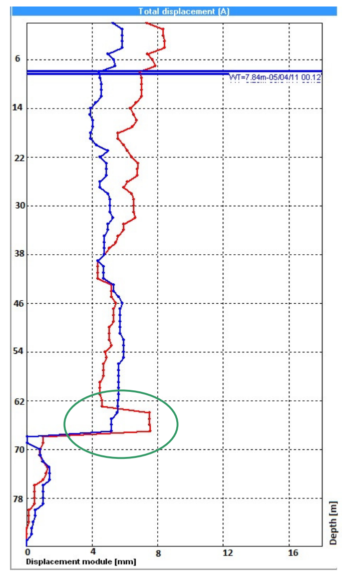


Figure 10: Total displacements of DMS_Ancona1

So was possible to detect a triggering event, between 63 and 68 m bgl, shown a month after the beginning of the pluviometric event.

On the second column, Ancona2, the water table level raised on the 1st of March at 00:00, 31 hours late (Fig 11).

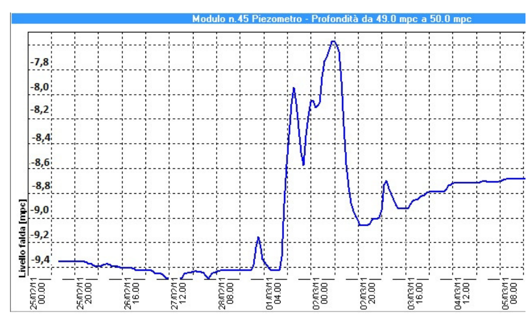


Figure 11: Water table level on DMS_Ancona2 site

The column detects some micromovements occurring after that (Fig 12):

- On module 14, depth 80-81 m, from 26/03/11 to 09/04/11
- On module 32 and 33, depth 61-63 m, from 26/03/11 to 09/04/11
- On module 58, depth 36-37 m, from 26/03/11 to 09/04/11

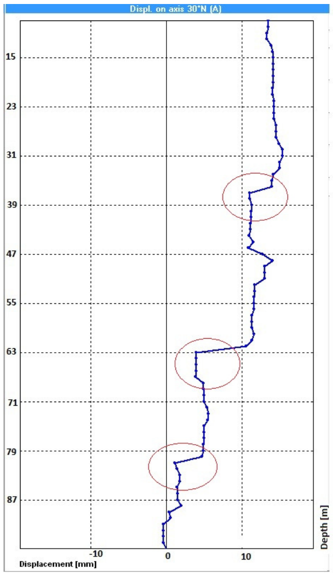

Figure 12: Total displacements of DMS_Ancona2

Figure 12 show three triggering events developed with a delay, like the previous, of one month.

On the last column, Ancona3, the same procedure was implemented. The water table level raised the 29th of February at 23:00, 30 hours late (Fig 13).

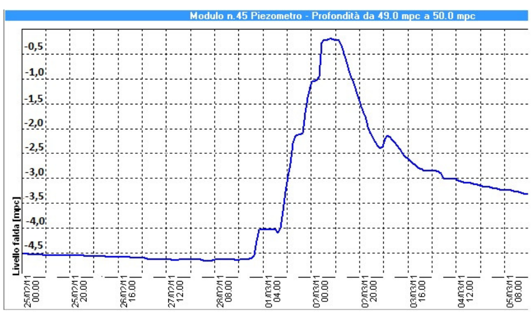

Figure 13: Water table level on DMS_Ancona3 site

In the analyzed period were not detected sensible indications, but a small events is shown by module 3, between 91 and 92 m bgl, from 19/05/11 to 21/05/11. This displacement could be very late than the rainfall event or caused by settlement.

The analysis shows a correlation of about 30 hours between the beginning of the rains and their effect on water table level and a month of delay with the occurrence of displacement phenomena. This data allow the implementation of a forecasting model and the evaluation of the risk level in function of more parameters, unlike traditional instruments.

It is important to notice that this analysis could not be achievable with only surface systems because developed on micro-movements occurring at significative depths.

## Conclusions

In this way, the Ancona administration has chosen the "LIVING WITH LANDSLIDE" policy: this new concept implies that the safety of the population is achieved through a high-quality and comprehensive early-warning system. This in contrast with the more static concept of standard engineering remedial works, which are clearly impracticable so far, in our case.

This project is the result of the best conjunction between human resources and a more reliable technology in the Early Warning monitoring field, put in use for a best safety and peacefulness for the people living on the Ancona landslide.

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