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GRAVITY-DRIVEN DEEP-REACHING DEFORMATIONS AND LARGE-SCALE LANDSLIDES IN RECENTLY UPLIFTED MOUNTAIN AREAS: THE CASE-STUDY OF MT. CUCCO AND BELPIANO (LIGURIAN APENNINE, ITALY)

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ABSTRACT

This work concerns with a DSGSD located in upper Sturla Valley (Northern Apennines, Italy), in the Municipality of Borzonasca, in an recently uplifted mountain area where the historic Belpiano hamlet was settled.

The investigation of DSGSD was carried out through field survey, historic maps comparison, drilling and monitoring activities; seismic surveys were carried out in order to define the depth of the bedrock not involved in the DSGSD.

The DSGSD origin is related to the slope particular geological structure with hard, fractured sandstones overlaying weak shales and characterized by a consequent high groundwater circulation supported by large amounts of rainfall, typical of this geographic area. Other DSGSDs have been studied and registered in this particular geological contest of Northern Apennines, actually in the Gottero Unit areas belonging to the upper Sturla Valley.

Clear morphotectonic and geomorphological elements of activity have been detected, in addition to rock blocks detached by the bedrock and sliding masses related to active landslides. The most significant phenomenon is the landslide which involved the ancient parish church of Belpiano during XVII century; another event occurred in 1982 when a heavy rainfall greater than 600 mm over 5 days caused a hydrogeological disaster involving the whole Sturla Valley.

Because of the large amount of rock and debris (ranging 320-480 millions of cubic meters) forming the sliding mass potentially affected by DSGSD and taking in consideration the erosional activity of Sturla river at the bottom of the slope and the actual climate changes it's reasonable to suppose that a reactivation, even partial, of DSGSD could create a landslide lake along the Sturla stream and a consequent high risk for several thousand people living downstream in the villages of Borzonasca, Mezzanego and Carasco.

Key words: *Deep Seated Gravitational Slope Deformation, landslide, Northern Apennines*

INTRODUCTION

In Ligurian Apennines, the Deep Seated Gravitational Slope Deformations (DSGSD) represent an important geomorphological landscape feature, both along the coast and in the hill-mountain environment (Zischinky, 1966; 1969; Nemcok, 1972; Savage & Varnes, 1987; Crosta, 1996; Crosta & Zanchi, 2000). Only recently they have been identified and accurately studied scientifically, unfortunately for the most part in a manner not suitable to their extension and complexity.

The attention towards these phenomena is linked to the important involvements brought by DSGSD in activities such town and land planning and environmental protection.

The acronym DSGSD refers to deep slope deformations associated with high energy-relief; generally the deformation value is small compared to the extension of the area affected by this phenomenon (Dramis

& Sorriso Valvo, 1994; Sorriso Valvo, 1995).

The most typical features of a DSGSD are the high number of tectonic lineaments and morphological elements produced by structural causes, the extension of the area afflicted which is often corresponding to the slope area, the small value of present displacements (in the order of few cm/year), the presence of significant landslides inside the deformed area (Agliardi *et alii*, 2001; 2009).

In the Liguria region, northwestern Italy, is relatively common to find different lithologies belonging to one of the two most important Italian mountain chains (Alps and Apennines) close to each other, in geomechanical and hydrological terms. The rock masses are often highly deformed, fractured and altered. Furthermore Ligurian Apennines are characterized by higher energy-relief, the Plio-Pleistocene tectonic lineations are particularly active, the seismic activity is significant, and important climate variations have been protracted all along the Quaternary (Faccini *et alii*, 2009a).

This paper is concerned with a DSGSD involving the entire system ridge, slope and valley floor, sited on the right side of the upper Sturla Valley (Ligurian Apennines) where an extensive and accurate site investigation was carried out.

The mountain side on which is located the village of Belpiano, hamlet of the Borzonasca Municipality, is historically affected by slope instability phenomena: through a long archival research it has been possible to identify some active landslides which caused the loss of several human lives starting from XVII century. Hence, our goal is to increase the scientific knowledge about this DSGSD, to pick out the deformation dynamics and to evaluate the actual geomorphological hazard.

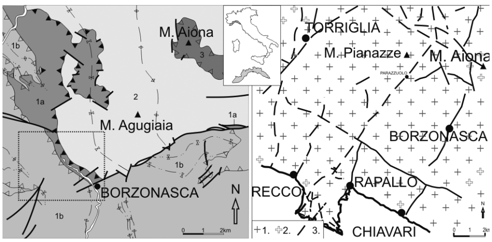

Fig. 1 - Location map of the studied area, tectonic and neotectonic sketch maps (modified from APAT, 2005 and Fanucci *et alii, 1980). Legend of tectonic sketch map (A): Internal Ligurides: 1. Gottero Tectonic Unit, Loco Subunit (a) and Ramaceto Subunit (b); External Ligurides: 2. Ottone Tectonic Unit; 3. Mt. Aiona Element. Legend of neotectonic sketch map (B): 1. Area affected by relative uplift; 2. Area affected by absolute uplift; 3. Fault*

Other large and complex geomorphological elements have been identified in the Sturla Valley (Brandolini *et alii*, 1991; De Stefanis *et alii,* 2001; 2002) but not related to other DSGSD. The analyzed portion of slope has been recently included among the regional areas under investigation of the IFFI project

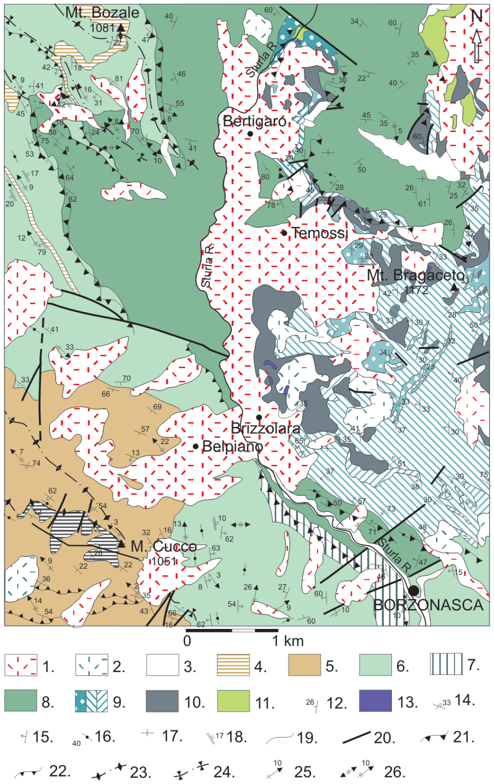

Fig. 2 - Geological map (modified from APAT, 2005). Legend: 1. Deposits mainly due to gravity; 2. Mainly colluvial deposits; 3. Alluvial deposits; 4. Argilliti di Giaiette (shales); 5. Arenarie di Mt. Gottero (sandstones); 6. Scisti Zonati (silstones and shales); 7. Olistostromi del Passo della Forcella (olistostromes); 8. Ardesie di Mt. Verzi (slates); 9. Argille a Palombini (shales with limestone interlayers); 10. Complesso di Casanova (a. Ophiolitic sandstones; b. Mono and polygenetic breccia with clayey matrix; c. Polygenetic breccia with sandy matrix); 11. Basaltic olistoliths; 12. Ultramafic olistoliths; 13. Cherts; 14. Normal beds; 15. Overturned beds; 16. Beds with uncertain polarity; 17. Vertical beds with uncertain polarity; 18. Horizontal beds; 19. Foliation of axial plane, 2nd phase; 20. Stratigraphic contact; 21. Faults, certain or assumed; 22. Main tectonic contact; 23. Secondary tectonic contact; 24. Trace of anticline axial plane; 25. Trace of syncline axial plane; 26. Axis of meso-fold, 1st phase; 27. Axis of meso-fold, 2nd phase

(Inventario Fenomeni Franosi in Italia, Bottero *et alii,* 2004) and in the SCAI project (Studio dei Centri Abitati Instabili, Federici *et alii*, 2004); however both the projects say there is no evidence of activity of the Belpiano DSGSD, therefore the mass wasting is considered ancient and relict.

In regard of the geographical location of the analyzed DSGSD, bordered at the bottom by a significant river and with several villages downstream (three of them, Borzonasca, Carasco e Mezzanego add up more than 7,000 people), not only more information about the dynamics of this gravitational phenomenon are required, but above all is necessary to monitor and keep studying it, remembering what happened during the catastrophic event of the Vajont landslide in 1963.

GEOGRAPHICAL AND GEOLOGICAL FRAMEWORKS

The investigated area is located on the orographic right of the Sturla river (Entella river catchment), upstream the village of Borzonasca (Fig. 1); its north boundary is the alignment between Mt.Cucco and Mt. Fracucco, while the southern one is the bottom of the Sturla Valley, covering a total length of 800 meters and an extension of 4 km^2.

The main settlement inside the DSGSD area is Belpiano (485 m a.s.l.); other smaller hamlets are located at a lower altitude (Frasineto at 343 m a.s.l.; Casa Mugè at 322 m a.s.l.) and some others at a higher elevation (Acero at 538 m, Cà dei Grilli at 720 m, Luvega at 781 m a.s.l.).

The climate of the area is defined by the parameters recorded at Tigliolo weather station (293 m a.s.l.) whose location is very close to the area under investigation: the prevailing climate is Mediterranean. The geographic setting and the main slope configuration of the Sturla Valley create an air mass circulation of wet and warm winds blowing from the Ligurian Sea.

Due to these conditions, relatively mild temperatures are generally observed, with an average of 13-14°C, with average annual rainfall of almost 2000 mm (maximum of annual rainfall level in the whole area of Liguria region). The average monthly rainfall distribution shows a maximum in November (250 mm) and a minimum in July (60 mm). Heavy concentrated rainfalls are often observed during the Fall season, when they can reach values as much high as half of the annual total only in a few days.

Geologic Formation	Description	Outcorp area
Argille a Palombini	medium-bedded limestone and medium to thick-bedded dark argillite	on the valley and the bottom of the slope on the orographic right, even if it belongs to the Bracco-Val Gaveglia Unit
Ardesie di Monte Verzi	marl, chalky amr and marly limestone medium to very thick-bedded, with sansotne and argillite thin interbeds	at the bottom of the slope under Arenarie del Monte Gottero and Argille a Palombini
Arenarie di Monte Gottero	siltstone, thin-bedded sandstone, argillite and marle medoim to thick interbeds; locally medium to coarse non-graded sandsotne	at the top of the slope and all along the ridge insede the investigated area
Argilliti di Giaiette	shales and siltstones thin to medium-bedde, with no lateral continuity	at a higher position above the Arenarie di Monte Gottero

Tab. 1 Description of geologic formations and related outcrop areas

The investigated area belongs to the tectonic domain of the Internal Liguride Units (APAT, 2005) and in particular to the Gottero Unit (Fig. 1): the upper and medium portion of the slope belongs to the Ramaceto Subunit, while the bottom of the slope belongs to the Loco Subunit. The tectonic contact between Internal Liguride Units and the Ottone Unit (belonging to External Liguride Units, whose overturned formations outcrop at the orographic left of the Sturla river) is located along the valley floor (Casnedi *et alii*, 1983; 1993). All the area is affected by a general uplift which started in lower Pleistocene, proved by several linear and areal features (Fanucci *et alii*, 1980).

The stratigraphic succession on the orographic right starting from the bottom to the top is made by Argille a Palombini, Ardesie di Mt. Verzi, Scisti Zonati and Arenarie di Monte Gottero, locally overlaid by portions of Argilliti di Giaiette (Fig. 2 and Tab. 1).

The Internal Liguride Units are characterized by a complex geological structure: during the period between Upper Paleocene and Lower Eocene these units were involved in a subduction process associated with the closure of the Ligurian-Piedmontese oceanic basin. The tectonic evolution of the internal Ligurian Units took place through two main deformational events associated with a compressional overthrusting which brought to a complex structural character.

The structural evolution can be well recognized in the Gottero, Bracco-Val Graveglia e Tavarone Units and therefore can be described in a single way (Marroni, 1991; Apat, 2005).

The first deformation event is defined by isoclinal folds with similar geometry; the hinge zone is generally thick and rounded, while the limbs appear thin and boudinaged. These folds are strongly non cilindrical with fold axis strike in a range from N160 to N30. These isoclinal folds are often associated with a slaty cleavage foliation which is clearly visible at the hinge zone while sometime it could be mixed up with the strata surface along the limbs.

The second deformation event is characterized by folds with parallel geometry, from gentle to tight interlimb angle, generally asymmetric and of various shape. The interlimb angle could vary in a range from a minimum of 30°/40° to a maximum of 100°/110°. The fold axis strike goes from N140 to N180. This second deformation event shows wide and extended reverse limbs associated with overturning of the figures originated during the first deformational event. Both in the first and in the second event an axial plane foliation classified as crenulation cleavage is recognizable. During the second deformational event a normal, extensional high angle fault system took place involving the Gottero Unit; strike angle of fault planes are included in a range between N160 and N20.

Large scale structural figures are visible along the upper Sturla Valley, where anticline folds belonging to the first deformation event inside the Ardesie di Mt. Verzi formation were deformed by gentle anticline and syncline folds belonging to the second phase.

After the first two deformation events a last geological phase took place during the Plio-Quaternary: an extension caused by the normal fault component of movement along the northern portion of the Apennines and a relative sequence of horst and graben areas. The analysis of the focal mechanisms related to a low seismic activity in north western Italy proves that the extensional Quaternary phase is still in progress.

METHODS

The knowledge of the geological and geomorphological features is essential to understand the evolution of a slope affected by DSGSD.

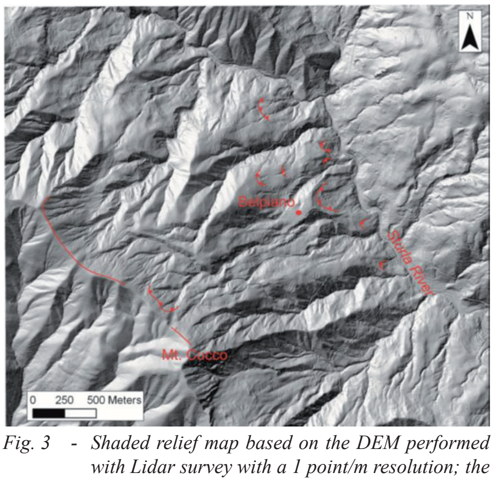

Fig. 3 - Shaded relief map based on the DEM performed with Lidar survey with a 1 point/m resolution; the main DSGSD and landslide scarps are indicated

The analysis of aerial photographs (Istituto Geografico Militare - 1954, scale 1:55,000 and Regione Liguria - 2006, flight no.73 scale 1:13,000) combined with geological and geomorphological field survey carried out at 1:5.000 scale revealed the presence of several different landforms and tectonic lineaments.

The study included a detailed survey of damage caused by DSGSD involving man-made structures, focusing on buildings, communication routes, reinforced-cement and dry-stone walls.

Particular attention has been pointed towards the geomorphological features related to neotectonics, directly associated with wide instability processes.

In order to represent the general morphological and deformational pattern, a digital elevation model (DEM) was obtained through different CAD/GIS packages (ESRI ArcGIS). A georeferenced contour map in a vector format obtained from a Lidar survey with a 1 point/m resolution has been prepared (Fig. 3); the DEM obtained in such way has been used to produce a shaded relief map. Morphometric analysis of the DEM outlined a lower sector with convex profile and a convex upper part: the slope shows a general saw tooth shape, whose angle of dip ranges from 26° to 36° between 950 m and 1050 m, between 800 m and 500 m and between 450 m and 250 m a.s.l.; the rate is lower than 11° between 485 m and 492 m and between 840 m and 890 m a.s.l., while at the remaining heights the slope angle of dip ranges from 11° to 26°.

A specific investigation was carried out through an accurate bibliographic research in historic archives, several interviews at the local residents and a computer research to catalog all the landslides which afflicted the area during the past centuries (Consiglio Nazionale delle Ricerche, 1994).

Particularly interesting was the research of historic maps which gave an important contribute to analyze the slope dynamics during the last centuries; here are reported the titles of the works: a) "Pianta delle tre ville d'Acero, Trigoso e Porcile con distanze, strade, boschi e corsi d'acqua" made by the Architect Sebastiano Ponsello and the painter Stefano Sturla, dated 1645 and preserved at the "Archivio di Stato di Genova"; b) "Carta del territorio compreso tra Genova, Spezia e il confine col Ducato di Parma", paper n.63, scale 1:9450, dated 1816-27 and preserved at the cartographic archive of the "Istituto Geografico Militare Italiano"; c) Boards in scale 1:25.000 "Borzonasca" property of "Istituto

Geografico Militare Italiano" 25v series, made in 1904 (first edition) and 1937 (third edition); d) Board in scale 1:25.000 "Borzonasca"by "Regione Liguria" - made with the contribute of aerial photography in 1992.

Many geomorphological and geological works pertaining to this area and focused on gravitational landforms and processes (Provincia di Genova, 2002) and other reviews about the landslide insisting on the investigated zone (Dramis *et alii*, 1985) were deeply analyzed to improve the general knowledge of the phenomena affecting this portion of Northern Apennines.

Within the project of mitigation of natural hazard of the slope affected by DSGSD on which is located the village of Belpiano, Regione Liguria promoted a field program consisting of 8 boreholes (3 continuous boreholes and 5 nucleus destruction drilling). The boreholes were carried out in the Belpiano area and reached 80 meters of depth (Tab. 2).

Borehole	I 1	I 2	I 3	P 1	P 2	P 3	P 4	P 5
Location (m a.s.l.)	490	480	477	487	481	478	485	481
Depth survey (m below g.l.)	80	50	50	30	30	30	30	30
Slide surface (m below g.l.)	25	22	46	-	-	-	-	-
Mean velocity (mm/y)	4	12	24	-	-	-	-	-
Water table (m below g.l.)	-	-	-	3,8-4,7	18,8-19,2	9,5 -10,5	5,9 - 7,0	12,2 -13,7

Tab. 2 - Drillings and slope monitoring data (I: inclinometer; P: piezometer)

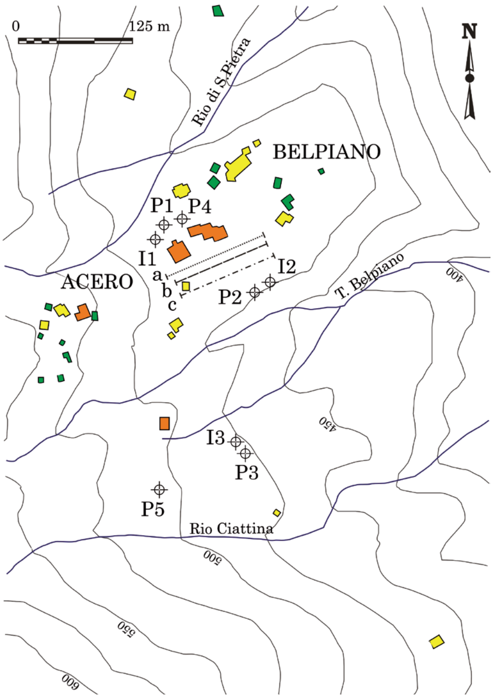

Fig. 4 - Drills and geophysical surveys location map with building damages classification (orange: high; yellow: medium; green: low). LEGEND: I. borehole with inclinometer case; P. borehole with piezometer case; a. seismic reflection trace; b. preliminary walk away noise test; c. seismic refraction trace

The boreholes were equipped with geotechnical and hydrogeological instrumentation: more specifically, three boreholes were instrumented with inclinometer case and five were instrumented with piezometer case (Fig. 4).

The monitoring activities were carried out for more than 3 years (2003-2007).

The field program has been integrated by both seismic refraction and reflection investigation (seismometer type Abem Terraloc Mark 6 with 24 channels) made along a 150 meters line and energizing the ground with some minibangs to the purpose of gaining more information about the mechanical condition of the portion of the bedrock potentially not involved in the DSGSD process.

RESULTS

FIELD SURVEY

A field survey was carried out at the slope portion between Casa Cugno (northern boundary) and San Rocco (southern boundary) revealing the presence of several different types of landforms, suggesting a complex evolution of the area during the uplift Quaternary phase of the Northern Apennines; this is proved by fluvial deposits found during some excavations 200 m above the present level of Sturla river.

Many other morphological features caused by neotectonics were found, such as a straight evolution of the ridge over the investigated slope, several depressions in correspondence with some recent tectonic lineaments and a large gravitational trench related to a tectonic cause parallel to the main ridge at 800 m a.s.l. (Fig. 5).

The drainage pattern has a mainly rectangular shape with many simple and double elbows alternated

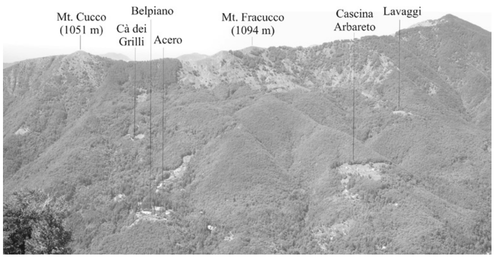

Fig. 5 View of the Mt. Cucco and Belpiano area. The upper sector of the DSGSD with the main scarp and Cà dei Grilli and Lavaggi ridge is shown

with straight segments; this complex trend suggests a main tectonic role during the evolution of the pattern.

Furthermore some triangular and trapezoid figures were found on the right bank of Sturla river, located between the valley floor at 250 m a.s.l. and the Belpiano village.

Debris cover characterizes a wide portion of the investigated area; these gravitational deposits are defined by different dimensions, genesis and kinematics while the few rocky outcrops marked in the investigated area are linked to rock blocks.

A relevant active landslide insisting on a flat area located south of Belpiano is the one starting from the northern side of Mt. Cucco and extending towards NE, more than one kilometer long and with a main flow kinematics (Fig. 6); standing on historic statements dated XVII century, a landslide occurred on this portion of the slope at the same level of the present village of Belpiano (Fig. 7), destroying the ancient parish church whose ruins are still visible. Another event occurred here in September 1982 when a heavy rainfall greater than 600 mm over 5 days was indicated as the main cause of a hydrogeological disaster in the Sturla Valley (Faccini *et alii*, 2009b).

Another significant landslide adjacent north to the previously described one insists on the hamlet of Belpiano; this landslide is complex, dormant and smaller than the active one. Other smaller gravitational events,

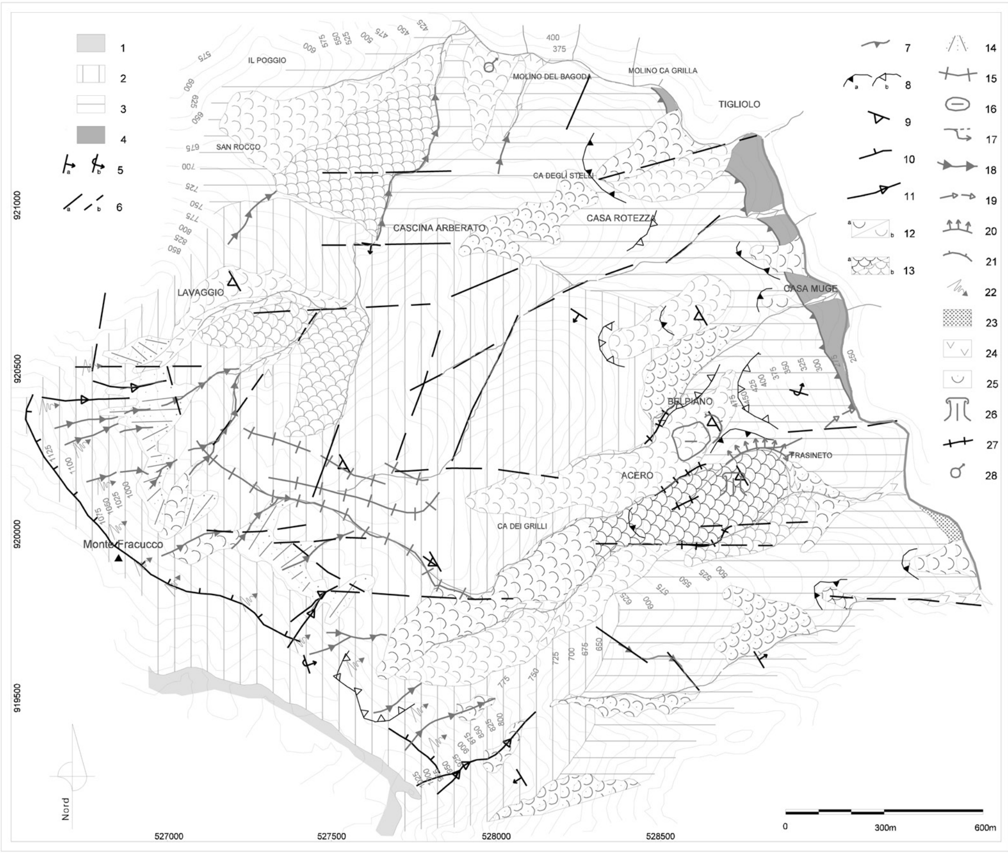

Fig. 6 - Geomorphological and morpho-structural map of the studied area. LEGEND: 1. Clayey shales; 2. Sandstone with thin interlayers of shales; 3. Clayey shales with siltstone layers; 4. Clayey shales with limestone layers; 5. attitude (a. dipped; b. overturned); 6. normal fault (a. certain; b. assumed or covered); 7. overthrust; 8. edge of scarp (a. active; b. inactive); 9. reverse slope; 10. edge of degradational scarp; 11. rock defile with rock fall; 12. landslide due to flow (a. active; b. inactive); 13. complex landslide (a. active; b. inactive); 14. scree slope; 15. trench; 16. closed depression; 17. river elbow; 18. downcutting stream; 19. abandoned stream; 20. riverbed with lateral erosion; 21. edge of erosion scarp; 22. widespread outwash; 23. alluvial deposits (sand and gravel); 24. debris flow; 25. colluvial deposits; 26. archaeological site; 27. main stream barrages; 28. springs

some of them still in activity, are identified close to the northern border of the DSGSD and at its bottom.

Several counterslopes give the mountainside a saw tooth shape with plain areas often delimited by uphill facing scarps irregularly interposed to steep rocky slopes alternating with small depressions filled with cohesive sediments – the village of Belpiano was settled on one of these deposits.

Degrading scarps and related scree slopes are visible under the watershed between Mt. Cucco (1051 m) and Mt. Fracucco (1095 m).

The geomorphological dynamics of the slope produces several damages on the buildings of Belpiano, especially cracks and ruptures mostly visible in the current parish church (built in 1661 by the monks of Borzone Abbey), cemetery buildings and school building; the ancient constructions also better show the damage caused by differential settlement and destabilizing loads on foundations and bearing walls. Along the streets surrounding the area some walls and gabionades are swelling because of hydraulic

pressure, especially next to torrents. Some maintenance works have been carried out during the last ten years to mitigate the water superficial erosion, but it wasn't enough to oppose the damaging action on embankments and retaining walls of the big amount of solid material carried downstream.

In consequence of high energy conditions, pluviometric profile and type of landslides the drainage pattern is deepening; furthermore the river beds of the streams belonging to the right riverbank of Sturla river such as T. Belpiano, T. Castellina and Rio Ciattina are often location of debris flows.

Fig. 7 - Historical maps of the studied area. - At the top: map of 1645 (Archivio di Stato di Genova); In the middle: map of 1816-27 (Archivio Storico dell'Istituto Geografico Militare Italiano); At the bottom: map of 1937 (Tavoletta dell'Istituto Geografico Militare Italiano). The red circle points out the position of the old church destroyed at the end of XVII century, while the blue circle points out the position of the present church

TECTONIC LINEAMENTS

Through an accurate field survey and the analysis of aerial photos it has been possible to identify more than three hundred tectonic lineaments related to several sets of extensional faults.

Four main sets of tectonic alignments have been identified: i) WNW-ESE striking, NNE subvertically dipping normal faults and joints system; ii) N-S and NNW-SSE oriented subvertical fractures; iii) SW-NE towards ENE-WSW striking joints and normal faults, steeply dipping to NW or SE; iv) E-W trending subordinate set of subvertical normal faults.

WNW-ESE and ENE-WSW (SW-NE) trending fracture systems are the most frequent in the area. This could suggest a recent reactivation of these structures, which seem to interrupt the continuity of the N-S (NNW-SSE) and E-W trending sets. This observations is in agreement with Fanucci *et alii* (1980) about the neotectonic framework of this part of Ligurian Apennine and with the orientation of the main DSGSD features reported in Fig. 6. These fractures strongly influence the trend of the valleys, such as the NW-SE and SW-NW general trending of the upper Sturla Valley and causing in such sector landforms like scarps (upper slopes of Mt. Fracucco). Trend analysis of photo-interpreted alignments performed by a GIS software enhances the influence of the WNW-ESE and ENE-WSW trending brittle structures on the drainage pattern in the right side of the upper Sturla Valley and consequently control the development of the DSGSD and landslides.

DRILLS AND GEOPHYSICAL TESTING

Through the drilling project carried out in the Belpiano area it has been possible to evaluate the minimum thickness of soil deposits related to landslide dynamics around 80 m (Tab. 2); despite of high values of depth reached none of the boreholes has encountered the top of the bedrock. This large amount of sediment consists of coarse debris made of gravel, pebbles and cobbles in a silt-sandy matrix (Canepa *et alii*, 2003).

The punctual results from drilling project has been extended to the whole area through an accurate geophysical investigation. Seismic of refraction investigation has been carried out for 150 m and the test results analysis contributed to make a three sequence seismic profile: the first identified level has seismic waves velocity values around 400-500 m/s and it has a high void ratio; in the second one seismic waves velocity values are included between 900 and 1100 m/s and it's identified as a soft soil with random boulders; the third and last one shows higher values of seismic waves velocity (between 1950 m/s and 2150 m/s) and its composition is considered similar to the second level but saturated because under ground-water level.

Seismic of reflection survey provided information that identified two main sequences: the first one consisting of landslide deposits in contact with the second one identified as the bedrock at a depth of 160-200 m. Furthermore two vertical discontinuities were identified: the first one, less visible than the second one in the test results, apparently doesn't affect the bedrock dip while the second one displaces the sandstone and shales beds accentuating their dip values (Fig. 8).

Data coming from inclinometer monitoring carried out for more than three years show activity signs on the south-eastern side of the flat area on which the village of Belpiano is settled: failure surface has been identified at a depth of 46 m below g.l., while another discontinuity has been determined at a depth range between 20 m and 25 m. Cumulative displacement at the top of the borehole indicates a landslide velocity ranging from 4 to 24 mm/year which is considered a very slow and extremely slow in the landslide velocity scale (Cruden & Varnes, 1996).

Standing on test results coming from seismic surveys, more weakness surfaces could be present at deeper level than the one reached through the drilling project.

Through groundwater monitoring it was found that the third soft soil level identified through seismic of refraction survey is an aquifer and that the water table is above the main slip surface with scarcely or no correlation with the rainfall data for this area.

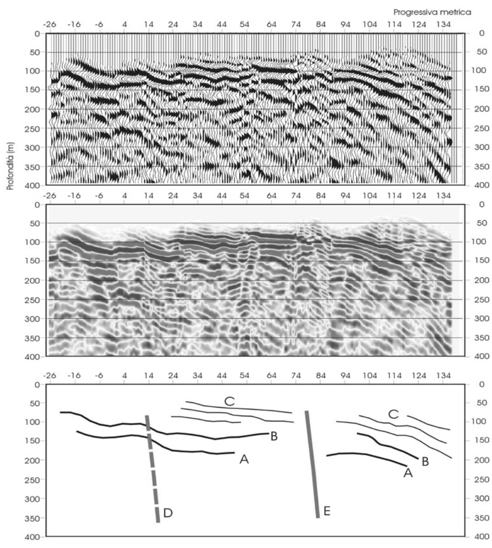

Fig. 8 - Seismic profile: A and B are main reflective surfaces (probably the top of the bedrock), C is a shallow reflective surface (mainly fine grained soil), D and E are subvertical discontinuities

DISCUSSION

Field investigations, drilling tests and geophysical surveys have significantly contributed to describe in detail an important deep-seated gravitational slope deformation affecting the entire slope between the Sturla river and the rectilinear ridge of Mt. Cucco and Mt. Fracucco.

The slope deformation consists of a large oblique "sagging" along a structurally controlled deep confined sliding surface and associated with recent gravitational reactivation of preexisting tectonic lineaments (Fig. 9).

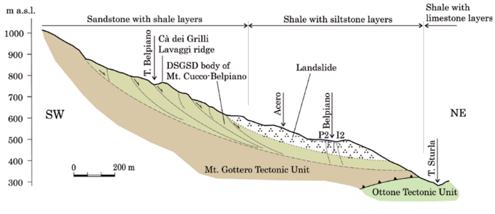

Fig. 9 - Geological and morphostructural cross section through a SW-NE trace (see Figg. 4, 6, 8 and Tab. 2)

The DSGSD caused the formation of mainly WNW-ESE trending trenches, double ridges, depressions, scarps and counterscarps.

The general contour of the mountain side is a saw tooth shape with upward dipping surfaces alternating with flat areas between almost 850 m a.s.l. and the valley floor of the Sturla river.

The evolution of the WNW-ESE and ENE-WSW trending systems caused the progressive bulging and failure of the lower part of the slope and is still in progress in the area of the active landslides.

The Cà dei Grilli and Lavaggi ridge has been displaced downstream with a NE component of motion; morphological and lithological markers suggest a downward displacement of 150-200 m in the upper part of the slope.

Starting from preexisting discontinuities, some listric faults associated to antithetical minor dip slip surfaces developed, forming asymmetric trenches.

The age of the DSGSD can be obtained from the relationship between morphostructural features and Quaternary landforms deposits (Brandolini *et alii*, 2008). Several swampy deposits characterizing the summit trenches related to other deep slope deformations in the Northern Apennines zone have been analyzed through radiocarbon dating (Branch, 2004): these sediments have been dated 11670±70 years BP, at the end of the Younger Dryas (Severinghaus *et alii*, 1998), therefore is plausible to assert that the deformation took place before that period.

On the basis of the available data three main factors are considered important for the understanding and modeling of the DSGSD evolution: the first one is a geological factor consisting of brittle layers overlaying ductile lithologies and a permeability difference between these formations with consequent high pore pressure values along the deep failure surface; the second one is the unloading and decompression of a fold and thrust belt structure caused by the deepening and undercutting of the slope mainly produced by river erosion; the third and last one is the periodic alternation of glacial and interglacial Quaternary phases.

Is possible indeed to identify the regional uplift of Ligurian Apennines during Plio-Pleistocene as the main endogenous reason for the tectonic lineaments system which contributed to shape the present slope counters of both the northern and southern mountain side of Northern Apennines and the actual coastline (Fanucci & Nosengo, 1979).

One of the most important tectonic lineaments is the NNE-SSW trending Sturla river fault which caused great mass displacements all along the Sturla Valley when the neotectonics earthquakes were stronger and more frequent than the present ones.

Despite the fact that a general geomorphological survey has been extended to the whole mountainside area, a deeper direct and indirect analysis has been carried out only in the middle and lower portion of the slope because of the major importance of that zone in the eyes of environmental risk.

The Belpiano area can be interpreted as a tectonic gravitational trench characterized by a counterscarp typical of sackungs (Bisci *et alii,* 1996; Dikau, 1999), filled up by fine sediments before and by fluvial deposits later because of the droop of the area.

In terms of geomorphological activity, many landslides of different type and dimension took place during the last century in this portion of territory involving several buildings and infrastructures; the most recent event is dated 1982, when the southwestern portion of the Belpiano hillock was hit by a landslide whose sliding mass reached the valley floor.

The preliminary results of the inclinometer monitoring system clearly indicate that the slope is subjected to a present state of activity, with a main slip surface at around 46 m below g.l., although it is evident that displacement could be active along deeper highly fractured horizons.

The lack of monitoring of the upper part of the slope prevents the assessment of activity. However morphological evidence observed through a field survey suggests inactive condition of the Cà dei Grilli and Lavaggi ridge, although low rate displacements along structural lineaments cannot be excluded.

It is legitimate to point out that wide and deep landslides as the one described in this paper have had an important role also in other ligurian valleys and especially in some adjacent ones: some DSGSDs belonging to Gottero Unit have been recognized in the lower Graveglia Valley (Brandolini *et alii*, 2007), in the upper Aveto Valley (Brandolini *et alii*, 2008) and in the Lavagna Valley (Capitani, 2010). These DSGSDs took place in the same previously described geological and tectonic contest also found in other mountain chains (Panek *& alii*, 2009), in which hard lithologies (like sandstone or marly limestone) are overlying weaker levels (shales). Even in these areas similar geomorphological and morphotectonic features are pointed out, like saw tooth shape of the mountainsides with small depressions filled with lacustrine cohesive sediments. The geomorphological risk of these other DSGSDs is comparable to the analyzed DSGSD affecting the hamlet of Belpiano and, in regard of the population density belonging to this hillside area, the consequent geomorphological hazard must be carefully evaluated in relation with the DGSGD evolution.

CONCLUSION

This work proposes an integrated multidisciplinary approach: the analysis of the mountainside in the upper Sturla Valley on which is settled the Belpiano village from a geological, structural, geomorphological and engineering-geological point of view through detailed field surveys, multi-temporary cartographic studies made at different times and in situ direct and indirect test programs has increased the understanding of a typical DSGSD case in Northern Apennines.

The knowledge of DSGSD in terms of town and land planning and environmental protection is important because of their closeness to several villages and hamlets: to this end, it must be told that the village of Belpiano has been recently renovated and consequently there will be a higher flow of tourism in the area.

Because of the large amount of rocks and sediments (3-4 hundreds of millions of cubic meters) forming the sliding mass potentially affected by DSGSD and taking in consideration the erosional activity of Sturla river at the bottom of the slope and the actual climate changes it's reasonable to suppose that a reactivation, even partial, of DSGSD could create a landslide lake along the Sturla stream and a consequent high risk for several thousand people living downstream in the villages of Borzonasca, Mezzanego and Carasco.

Furthermore during the last years due to the particular morphoclimatic condition of the Gulf of Genoa many flash floods have hit the central portion of Liguria (Faccini *et alii*, 2012) and this clearly represents a further destabilizing factor for wide landslide areas (Hendron & Patton, 1985); for example in 1970 during the Genoa flooding event 750 mm of rain water fell in less than 24 hours while in 1982 in the upper Sturla Valley 540 mm of rain water fell in almost 24 hours.

A further implementation of geotechnical and hydrogeological monitoring activities is recommended to obtain more data and information about the DSGSDs dynamics in different areas and time periods, especially for the active ones. Data obtained from Interferometric Synthetic Aperture Radar (InSAR) monitoring combined with the installation of radar targets in the area could also be extremely useful for this purpose.

The investigation of the Mt. Cucco and Belpiano DSGSD is to be considered at its beginning and should be extended to other portions of upper Sturla Valley; indeed several geomorphological elements suggest a wider extension of the studied phenomena, therefore different areas of the valley on both riverbanks related to the general overthrusting of Internal Liguride units on the External ones could be involved.

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