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ON THE PRESENCE OF FLUVIO-LACUSTRINE DEPOSITS ON THE POMARICO HILL (MATERA): INTERPRETATION AND ENGINEERING GEOLOGY RELEVANCE

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EXTENDED ABSTRACT

Il paese di Pomarico sorge sulla sommità di una dorsale tra le valli dei fiumi Bradano e Basento ed è costituito dai termini del ciclo regressivo marino plio-pleistocenico della Fossa Bradanica. Estese indagini di campo e di laboratorio hanno messo in luce, in un settore della dorsale, la presenza di terreni litologicamente diversi da quelli della serie stratigrafica plio-pleistocenica tipica.

Le analisi micropaleontologiche hanno indicato che si tratta di depositi riferibili al Pleistocene successivi ai Conglomerati di Irsina e la presenza di gesso indica un ambiente di tipo fluvio-lacustre, sino ad evaporitico. Le analisi mineralogiche indicano una composizione qualitativamente simile a quella delle Argille Subappennine, ma con una maggiore quantità di montmorillonite, che potrebbe derivare da processi di alterazione e trasformazione dall'illite. I due sondaggi effettuati nell'area di diretto interesse indicano la presenza delle Argille Subappennine ad una profondità di circa 21 m dal p.c., al letto di circa 8-10 m di sabbie limose o limoso-argillose, ocracee, ben addensate, attribuibili alle Sabbie di Monte Marano. Seguono conglomerati con intercalazioni sabbiose, talora cementati, attribuibili ai Conglomerati di Irsina. La serie termina verso l'alto con sedimenti continentali dapprima limoso-argillosi e quindi sabbioso-limoso-ciottolosi dello spessore complessivo di circa di circa 8-10 m (Figure 1 e 3).

Le analisi mineralogiche (Tabella 1) indicano una composizione qualitativamente simile a quella delle argille subappenniniche, ma con una maggiore quantità di montmorillonite, non comune nelle Argille Subappenniniche. Le analisi micropaleontologiche indicano che questi depositi sono certamente successivi al riempimento del bacino bradanico ed all'emersione della paleosuperficie regressiva e la presenza di gesso denota un ambiente deposizionale di tipo evaporitico. Le caratteritiche geotecniche sono state determinate principalmente sui depositi fluvio-lacustri, e su alcuni campioni delle Fm. delle Sabbie di Monte Marano e delle Argille Subappennine (Figure 4, 5 e 7). I depositi fluvio-lacustri coesivi sono classificati come argille o argille limose inorganiche, molto plastiche ed inattive, da poco a mediamente sovraconsolidati, con moduli edometrici alquanto bassi. Le caratteristiche fisico-meccaniche differiscono sostanzialmente da quelle delle Argille Subappenniniche per la presenza significativa di montmorillonite che determina una minore resistenza al taglio ed una più alta compressibilità. I soprastanti livelli sabbiosi incoerenti risultano da mediamente a poco addensati e dotati di compressibilità generalmente modesta. In Tabella 2 sono riassunti i valori medi dei parametri geotecnici ottenuti dalle prove di laboratorio e dall'interpretazione delle prove sismiche a rifrazione. Ai soli fini delle successive analisi di stabilità sono riportati anche i valori medio-minimi dei parametri di resistenza al taglio ottenuti riducendo le resistenze medie di una quantità pari alla rispettiva deviazione standard. Al fine di valutare la rilevanza della presenza dei depositi fluvio-lacustri sono state eseguite, sul versante maggiormente acclive, alcune analisi di stabilità utilizzando il codice FLAC 2D, assumendo inizialmente i valori di resistenza al taglio medi. Con queste caratteristiche la stabilità del pendio esaminato è assicurata (FoS = 1.46) anche in presenza di una falda idrostatica quasi al piano campagna. Considerando i parametri di resistenza al taglio medio-minimi nelle stesse condizioni idrauliche si è ottenuto lo stesso fattore di sicurezza (FoS = 1.46), un risultato che mette in luce l'irrilevanza della presenza dei depositi fluvio-lacustri sulle condizioni di stabilità dell'intero versante. I depositi fluvio-lacustri sono, però, interessati da incrementi, anche se molto limitati, delle massime deformazioni di taglio che sottolineano il loro differente comportamento rispetto alle formazioni sottostanti. Si è tenuto, quindi, conto della sismicità dell'area che potrebbe avere indotto deformazioni cicliche tali da ridurre significativamente le resistenze disponibili. La provincia di Matera, caratterizzata da terremoti relativamente frequenti (più di 140 negli ultimi 5 anni) di magnitudo M=1.5± 0.5, appartiene alla 3a categoria sismica, caratterizzata da accelerazioni orizzontali pari a 0.15g. Le analisi pseudo-statiche con gli stessi valori medio-minimi delle resistenze al taglio mostrano che non si raggiunge la condizione di equilibrio ed il fattore di sicurezza collassa ben al di sotto della condizione di equilibrio limite (FoS = 0.31). Tutti i depositi fluvio-lacustri al di sopra dei Conglomerati di Irsina risultano plasticizzati e, poiché i fenomeni di dilatazione sono più accentuati con pressioni di confinamento basse, questo risultato potrebbe giustificare i fenomeni di creep osservati e le piccole frane poco profonde presenti nell'area.

In conclusione le indagini effettuate hanno messo in luce in un'area dell'abitato di Pomarico (Località Serre) la presenza di depositi fluvio-lacustri ben differenziati dal punto di vista geomeccanico dai terreni della serie plio-pleistocenica bradanica. Il test di analisi di stabilità mostra che la loro presenza deve essere attentamente individuata e le loro caratteristiche accuratamente determinate. Nel lungo termine, infatti, qualsiasi modifica, anche minima, dello stato tensionale potrebbe indurre problemi non trascurabili anche su versanti poco acclivi.

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ABSTRACT

The village of Pomarico stands on top of a ridge between the valleys of the Bradano and Basento Rivers (Southern Italy) and is formed by the terms of the Plio-Pleistocene marine regressive cycle of the Bradanic Foredeep. In this area, the presence was observed of post-regressive alluvial facies in non-conformable contact with the underlying formation.

This paper, based on an extensive engineering geological survey, reports the find of deposits rather different from those typical of the local stratigraphic series. The micropaleontological analyses indicate that these deposits are referable to Middle-Upper Pleistocene, suggesting a marsh or pond environment subsequent to the filling phases of the sedimentary basin and the following emersion. X-ray diffractometric analyses indicate a mineralogical composition similar to that of the Subapennine Clays, with a predominance of montmorillonite among clay minerals.

The higher amount of montmorillonite results in significantly lower shear strength and higher compressibility values, entailing a different general behaviour with respect to natural or human-induced stresses. In order to highlight the relevance of their presence, numerical stability analyses were performed on a slope characterised by the presence of these deposits, also taking into account the seismicity of the area. The results seem to justify the surface creep phenomena and the small shallow landslides that characterise the area.

Keywords: *fluvio-lacustrine deposits, micropaleontological analysis, mineralogical composition, geotechnical properties, numerical analysis, Bradanic Foredeep*

INTRODUCTION

The village of Pomarico stands on top of a ridge between the valleys of the Bradano and Basento Rivers and is formed by the terms of the Plio-Pleistocene marine regressive cycle of the Bradanic Foredeep (Boenzi *et alii*, 1971).

The Bradanic Foredeep is a narrow Pliocene–Pleistocene sedimentary basin with a NW-SE trend, developed between the southern Apennines to the west and the Apulian foreland to the east. The in-fill successions of the marine regressive series are more than 1000 m thick. In the Middle Pleistocene the Bradanic Foredeep began to uplift, inducing the ancestral rivers to cut deep valleys perpendicularly to the coast and to erode the gradually forming hillslopes. The result was the progressive exposure of the highly erodible clayey bedrock, a contemporary increased cutting of deep lateral gullies and the triggering of even large landslides. The uplift is also evidenced by the fluvial Pleistocene and Holocene terraces (Boenzi *et alii*, 1971).

The geological setting of the Bradanic Foredeep has always aroused great interest in the scientific community for its structure and geomorphological evolution (Crescenti, 1975; Balduzzi *et alii*, 1982; Casnedi, 1988; Lazzari, 1999; Bentivenga, 2004).

Only recently, particular attention has been paid to the in-depth study of the basin's sedimentary history and associated structural features, as important diagnostic elements for reconstructing the causes and modalities that favoured the filling of the basin itself. The presence of post-regressive alluvial deposits has been recognised in some places; these sediments consist mainly of conglomeratic or rarely sandy facies, strongly reddened, placed in non-conformable contact with the underlying unit. Their deposition can be referred to alluvial episodes subsequent to the in-fill phases of the basin and the emersion of the regressive paleosurface, thus not belonging to the regressive sequence itself (Piccarreta & Ricchetti, 1970; Sabato, 1996; Sabato *et alii*, 2004; Cilumbriello, 2008; Lazzari, 2008). In particular, Tinelli *et alii* (1992) recognised the presence of similar deposits in a ditch immediately northeast of Pomarico.

This article is based on the results of an extensive geological and geotechnical survey campaign and aims to report the finding in the area of Pomarico of a significant presence of continental deposits, referable to a lacustrine or brackish basin above the closure deposits of the marine regressive cycle. These deposits were analysed from a stratigraphic, mineralogical, palaeontological and geotechnical point of view in order to define both their origin and physical-mechanical characteristics for engineering geological purposes. The new urban settlements, due to the instability of the old villages located on hilltops, often develop on plateaux apparently without any particular problems but which actually require specific in-depth studies (Cotecchia, 1957; Guerricchio & Melidoro, 1979). This is the case of Serre, a neighbourhood of Pomarico, which since the 1970s has witnessed a progressive urban expansion pushed as far as the edges of the flat top area.

GEOLOGICAL SETTING

The Bradanic Foredeep is a tectonic graben structure, originated as a result of the development of a system of extensional faults due to the subsidence of Mesozoic carbonate sediments to the west of the present-day Apulian platform. The latter constitutes, thus, the bedrock of the stratigraphic units of the Plio-Pleistocene sedimentary cycle, extending between the foreland, represented by the Apulian carbonate units to the east, and the Apennine range formed by allochthonous materials in flysch facies to the west. The succession of tectonic events, which developed on the western edge of the Bradanic Foredeep, caused on several occasions a change in the environmental and depositional characteristics of the sedimentary basin. Following the Late Miocene tectonic phase, which had led to the uplift of the Apennine arc, the marine sedimentation was influenced by the arrival of Apenninic units during the infra-pliocene tectonic phase determining significative shifts towards the east of the foredeep basin.

The stratigraphic series of the Bradanic Foredeep is given, starting from the most ancient deposits, by three main stratigraphic units in depositional continuity (Lazzari & Pieri, 2002; Lazzari, 2008): the 'Subapennine Clays' Fm., the 'Monte Marano Sands' Fm., and the 'Irsina Conglomerates'Fm.. The Subapennine Clays Fm. (early Pleistocene) consists of clays, marly clays and clayey silts, grey-blue coloured, deposited in a shallow sea environment, containing frequent thin layers of fine to medium fine grained sands; the surface level takes on a yellowish colour due to intense alteration phenomena. The stratification, highlighted by the presence of the silty-sands layers, generally shows an inclination of 5° to 15° to the south-east. The Monte Marano Sand Fm. (middle to early Pleistocene) is given by quartzose-feldspathic sandy deposits in a carbonate matrix, incoherent to weakly cemented, yellowish grey to yellow ochre in colour. The grain size composition, fairly heterogeneous, contains varying percentages, sometimes significant, of silty-clays. There are also layers of strongly cemented arenites showing a distinct stratification in agreement with that of the underlying 'Subapennine Clays'. They assume maximum thicknesses of approximately 10-15 m. The Irsina Conglomerates Fm. (middle to early Pleistocene) represents the termination of the marine regression. It is composed of polygenic and heterometric element, sometimes with yellow-reddish sands levels or banks. They assume maximum thicknesses of approximately 50 m.

Geological, hydrogeological and geomorphological setting of the area

The typical stratigraphic series of the Bradanic Foredeep outcrops in the study area. On the basis of geognostic data and field surveys, the top of the Subapennine Clays is found at an elevation of about 430 m a.s.l, covered with approximately 15-20 m of Monte Marano Sands and 8 -10 m of Irsina Conglomerates. In the Serre locality (Pomarico area), fluvio-lacustrine deposits (probably late to middle Pleistocene) were found (Figure 1).

These sediments rest directly on the Irsina Conglomerates, and consist of silty clays underlying sandy conglomerates with a maximum thickness, evidenced by boreholes, of approximately 8-10 m. The silty-clayey deposits, from light green to havana and blue-grey coloured, present ochre and blackish spreads and dots. They usually contain small amounts of medium to fine-grained sands and frequent whitish calcareous concretions. These deposits outcrop between approximately 452 and 460 m a.s.l.. The sandy conglomeratic deposits overly the silty-clayey deposits, but they can be found seldom directly in contact with the underlying regressive conglomerates. Reddish or reddish-brown coloured, they consist of dense to medium dense heterogeneous, heterometric and well rounded pebbles in a gravelly-sandy to silty-clay matrix. They are located at elevations above 460 m a.s.l. and have a maximum thickness of approximately 4-5 m.

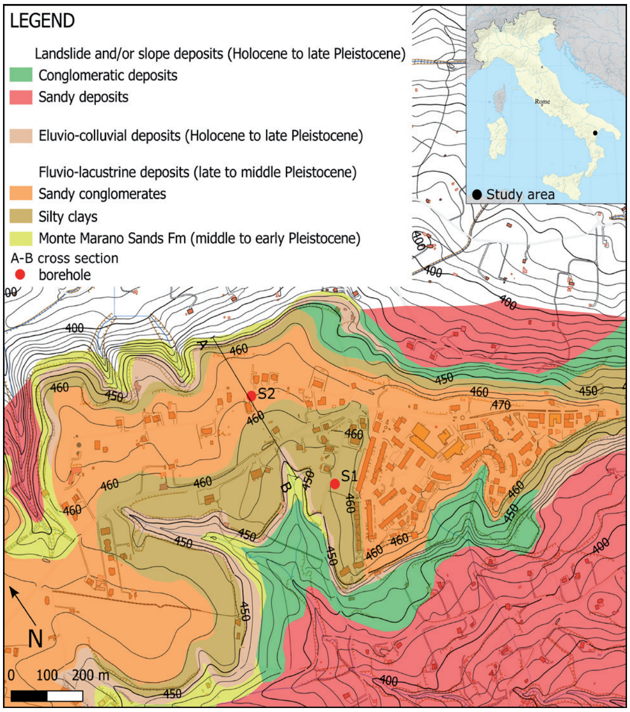

Fig. 1 - Geological map and study area location

Heterogeneous continental sediments (Holocene to late Pleistocene) cover the slopes: they consist of eluvio-colluvial deposits and sandy or conglomeratic landslide and/or slope deposits.

The numerous wells drilled over the years have indicated the presence of a superficial temporary aquifer, contained in the fluvio-lacustrine sandy-gravelly deposits and supported by the deeper clayey levels. The main aquifer is represented by the Monte Marano Sands Fm., characterised by medium-high to high, largely variable permeability and considerable anisotropy due to the presence of thin silty-clayey levels. The arenitic levels are characterised by relatively high secondary permeability.

The examined area is located on a morphological terrace whose conglomeratic-sandy escarpments at the edges correspond very often to the crown of ancient massive landslide phenomena now considered stabilised or quiescent (Floris, et al., 2004). In the area, accelerated erosional phenomena are widespread especially during rainfall of even medium intensity, as a consequence of diffuse and channelled runoff phenomena, particularly at the edges of the terrace.

The erosional processes are frequently accompanied by soil creep (Figure 2) causing the downslope movement of soil and potentially the transition from stable deformation to shallow instability failure, as occurs especially on the slopes of the small lateral tributaries of the two main ditches that flow in a northwest-southeast direction north and south of Pomarico respectively.

Fig. 2 - Soil creep phenomena at Serre area

MINERALOGICAL AND MICROPALEONTOLOGICAL CHARACTERISTICS

Four samples were taken in the boreholes at different depths on which X-ray diffractometric analyses were performed on the silty-clayey fraction (< 63 µm). The analyses revealed a mineralogical composition consisting mainly of clay minerals, carbonates, quartz and feldspars, as well as accessory minerals such as gypsum, pyrite and garnet. In particular, the clay minerals are represented by smectite, illite and muscovite, chlorite, kaolinite and mixed illite/kaolinite layers (Lupo, 1992). The results are summarised in Table 1.

Borehole	Depth (m)	S	I+Mu	K	Cl	Qz	Fl	Ca
S1	4.5-5.0	25	19	14	7	10	6	19
S2	4.0-4.5	21	20	17	9	12	6	15
S2	4.8	25	19	11	7	10	5	23
S2	12.0	22	18	8	4	23	10	15

Tab. 1 - Mineralogical composition of the fluvio-lacutrine deposits. Quantities in (%). S: Smectite; (I+Mu): Illite + Muscovite; K: Caolinite; Cl: Clorite; Qz: Quartz; Fl: Feldspars; Ca: Calcite

The mineralogical composition of the fluvio-lacustrine deposits differs from that of the Subapennine Clays where the illite fraction is dominant compared to the smectite (mainly montmorillonite), while the quantities of the other minerals are comparable. They also contain non-negligible amounts of mixed disordered illite-smectite layers, which are infrequent and not abundant in Subapennine Clays (Dell'Anna *et alii*, 1974; De Marco & Di Pierro, 1981).

The same samples were analysed from a micropaleontological point of view. Fossil remains, mainly consisting of mollusc shells, benthic foraminifera and ostracods, are numerous and fairly well preserved. The fossil record gives a precise environmental indication, but does not provide really useful information on its geological age, which may be generally ascribed to the Pleistocene epoch. In general, the results indicate an oligo-mesohaline environment, represented by a marsh or a pond completely closed to all marine influence and in which fauna and flora (Ammonia beccari, Cyprideis torosa, Hydrobia) thrived. The association found in a sample at a depth of 12 m seems to indicate an environment closer to the fluvio-lacustrine to which the same species would have been flowed.

FIELD AND LABORATORY INVESTIGATIONS

Several boreholes have been drilled in the study area to a maximum depth of 30 m along with a number of refraction seismic profiles to identify the stratigraphy and the lithological characteristics of the area. In order to obtain useful information about the stratigraphic and tectonic structure, the surveys were extended to a wider area than the one considered. The two boreholes carried out in the area of direct interest, below the approximately 2 m thick cover of topsoil, show the presence of:

- up to a depth of about 8.0 – 9.0 m: pebbly silty sands at the top and clayey silts and silty clays at the bottom, light green to havana coloured, hardly plastic, in a solid-plastic state, attributed to the fluvio-lacustrine deposits;
- up to a depth of approximately 13 m: conglomerates with polygenic heterometric elements, with thin sandy intercalations, dense to very dense, corresponding to the Irsina Conglomerates Fm.;
- up to a depth of approximately 21 m (S1) and 34 m (S2): dense to very dense, yellow ochre, silty sands with silty-clayey layers, attributed to the Monte Marano Sands Fm..

The recognised lithological sequence lies everywhere on the Subapennine Clay Fm. and the difference in the elevation of occurrence can be attributed to the presence of a small buried fault that lowered this Formation in the southwestern sector of the area.

Six seismic refraction profiles carried out in this area identified the thicknesses, as well as some properties, of different soils in the sequence and provided some indications on the probable existence of some buried faults outside the investigated area. The seismo-stratigraphic profiles show the presence in the study area of 4 levels, characterised by pressure wave velocities increasing from top to bottom from 400-600 m/s to over 2,000 m/s, corresponding to the lithological sequence identified by the boreholes. Figure 3 displays the geo-lithological cross section.

Numerous samples of different quality classes (Eurocode 7, 2007) were taken in the boreholes for the laboratory determination of geotechnical characteristics. The physical-mechanical characteristics were defined with particular reference to the two boreholes carried out in the restricted study area. 11 undisturbed samples (class A) were taken in the Subapennine Clay Fm. and 3 partially disturbed samples (class B) in the Monte Marano Sands Fm.. 17 undisturbed samples (class A) were taken in the cohesive levels of the the fluvio-lacustrine deposits, and

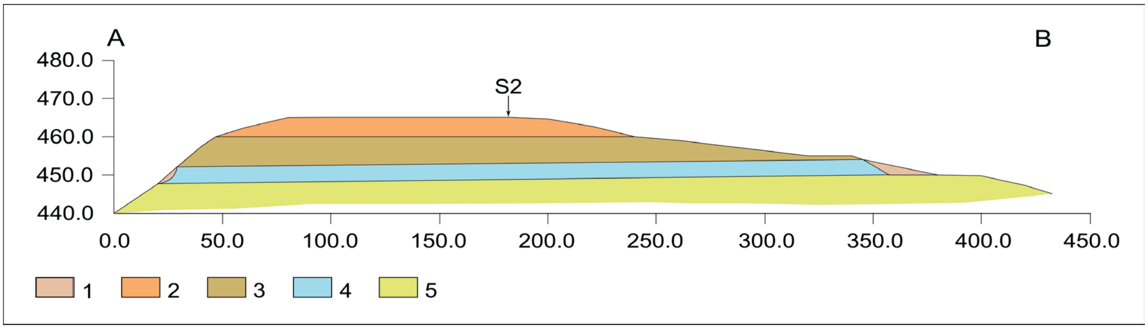

Fig. 3 - Geo-lithological section. 1: Eluvio-colluvial and/or landslide deposits; 2: Sandy conglomerates; 3: Silty clays; 4: Irsina conglomerates Fm.; 5: Fine and coarse sands; S2: borehole. Vertical exaggeration (horizontal/vertical scale): 2

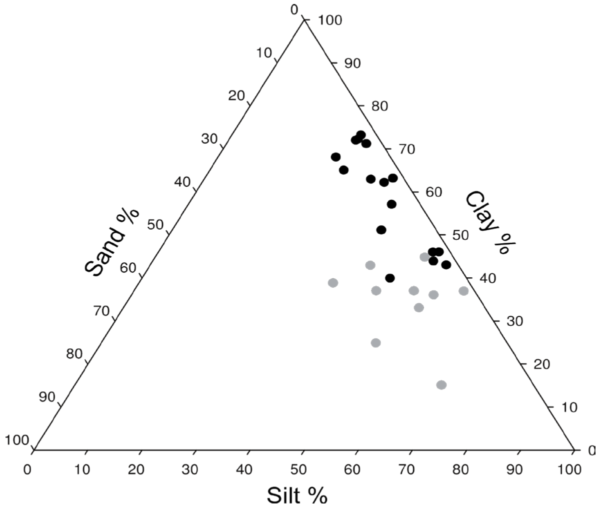

Fig. 4 - Triangular classification of U.S. Public Roads Administration. Black dot: Fluvio-lacustrine clays; Grey dot: Subapennine clays.

4 partially disturbed samples (class B) in the silty-sandy levels.

The cohesive fluvio-lacustrine deposits are classified granulometrically as clays or silty clays (Figure 4) and, based on their plasticity, as highly plastic inorganic clays (CH) (Figure 5).

In relation to colloidal activity, these soils are almost exclusively inactive (Skempton, 1948). They are little to medium overconsolidated, with a preconsolidation pressure of about 350 kPa and a low oedometric moduli (M=2-4 MPa). The fluvio-lacustrine cohesionless levels are classified granulometrically as slightly clayey sandy silts with a low to very low compressibility (M > 100 MPa). The shear strength characteristics were determined by consolidated drained direct shear tests (Figures 6 and 7) and unconfined compression tests.

Bulk and shear modulus values were derived from the initial tangent modulus of elasticity, obtained by unconfined compression tests with a Poisson coefficient of 0.4 for cohesive levels and 0.25 for incoherent levels. Elastic moduli of not coherent soils were derived from existing correlations with elastic wave velocities and from the reference literature (e.g. Deere & Miller, 1966; Hunt,2005).

The average values of the shear strength parameters (Table 2) correspond to those of the regression line calculated for all obtained results (Figures 6 and 7) and are comparable with those in literature (Genevois *et alii*, 1984; Cherubini *et alii*, 2002).

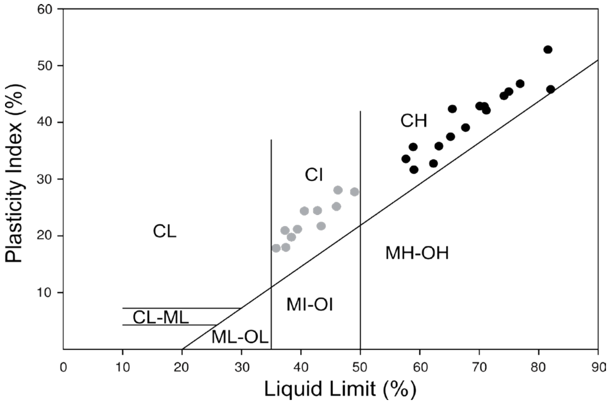

Fig. 5 - Casagrande Plasticity Chart. Black dot: Fluvio-lacustrine clays; Grey dot: Subapennine clays

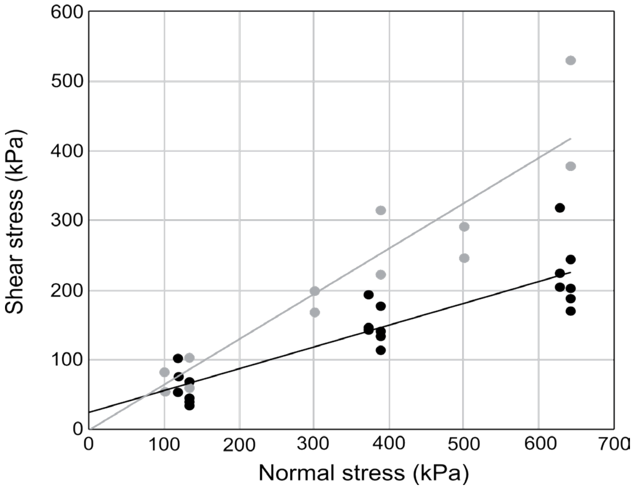

Fig. 6 - Linear regression failure mean envelops of fluvio-lacustrine soils. Black dot: cohesive levels. Grey dot: cohesionless levels

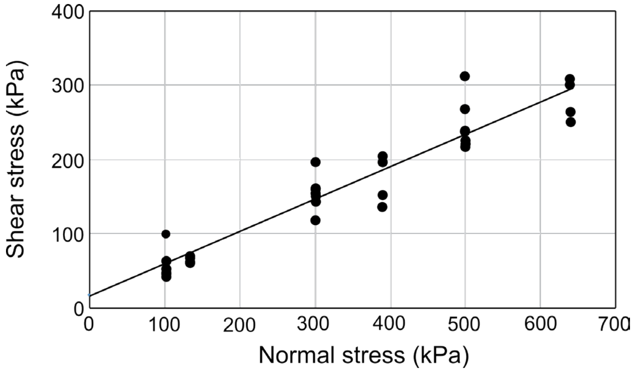

Fig. 7 - Linear regression failure mean envelope of Subapennine Clays

For the purposes of the stability analysis, these parameters were also calculated for the regression line obtained by considering the shear strength values reduced by the corresponding standard deviation (reduced values of Table 2).

	ρ (kg/m³)	c' (kPa)	c'* (kPa)	φ' (°)	φ'* (°)	UCS (kPa)	K (GPa)	G (GPa)
SAC Fm	2010	21		27.5		356	3.33	0.71
MMS Fm	1900	0		32.0		---	4.67	2.82
IrC Fm (a)	2100	100		40		---	5.56	4.17
Fl-c	1800	24.5	9	17.4	15.0	67.1	0.82	0.11
Fl-s	1820	0	0	30	26.2	---	1.65	0.40

Tab. 2 - Geotechnical parameter values. ρ: density; c': mean drained cohesion; c': drained cohesion reduced value considered; φ': mean drained friction angle; φ'*: drained friction angle reduced value considered; UCS: Unconfined Compressive Strength; K: bulk modulus; G: shear modulus. SAC Fm: Subapennines Clay Formation; MMS Fm: Monte Marano Sands Formation; IrC Fm: Irsina Conglomerates Formation; Fl-c: Fluvio-lacustrine clays; Fl-s: Fluvio-lacustrine sands*

STABILITY ANALYSIS

In order to verify the effects of the presence of the fluvio-lacustrine levels on the overall slope behaviour in the study area, a stability analysis was performed on the steepest slope of the area, to the south of borehole S1 (Figure 1).

The analysis was carried out using the code FLAC (Fast Lagrangian Analisys of Continua) (Itasca, 2016), a two-dimensional explicit finite difference program that simulates the behaviour of soil, rock or other materials that may undergo plastic flow when their yield limits are reached. Calculation scheme and the mixed-discretization zoning technique used ensure that plastic collapse and flow are modelled very accurately (FLAC 8, 2016). The geometric model, consisting of a 3500-mesh grid, is illustrated in Figure 8 by the distribution of soil density values and a Mohr-Coulomb plasticity model has been adopted for all soils.

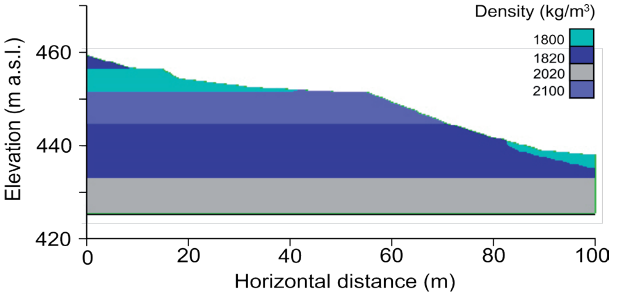

Fig. 8 - Geotechnical model displayed by the distribution of density values

The average values of the shear strength parameters (Table 2) were initially adopted in the analysis, while considering a condition of almost total saturation of the soils, possibly generated by particularly heavy long rainfall. With these values, unbalanced forces reached the required equilibrium, no significant horizontal displacements are observed and the safety factor (FoS) results 1.46. An identical value of the factor of safety is obtained using the shear strength reduced values (Table 2), thus demonstrating the irrelevance of the presence of the fluvio-lacustrine levels on the stability conditions of the entire slope. This is confirmed by the distribution of the maximum shear strain increments, chosen to depict the state of the slope: only the fluvio-lacustrine deposits are affected but by substantially insignificant deformation (Figure 9).

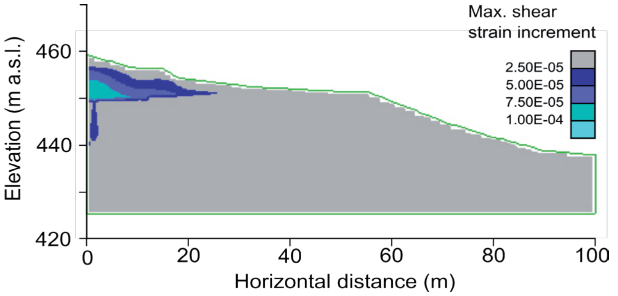

Fig. 9 - Shear strain increment involving all the fluvio- lacustrine deposits and, in part, the top of the Irsina Conglomerates

In order to take into account the worst possible conditions, it was taken into account that the province of Matera is a seismic area characterised by frequent (more than 140 in the last 5 years) earthquakes of mean magnitude M=1.5± 0.5 belonging, according to the Italian standards, to the 3rd seismic category characterized by horizontal accelerations of 0.15 g (G.U., 2003). Pseudo-static analyses were then performed, using the indicated horizontal acceleration and the same reduced values for fluvio-lacustrine deposits as in Table 2.

In these conditions, the equilibrium is not reached: all the fluvio-lacustrine deposits above the Irsina Conglomerates yield (Figure 10) and the safety factor collapses to FoS = 0.31.

Maximum shear strength increments are concentrated at the base of fluvio-lacustrine deposits in a relatively thin band (Figure 11) and indicate that a roto-translational landslide could involve the entire fluvial-lacustrine deposit. The relevance of seismic stresses is also

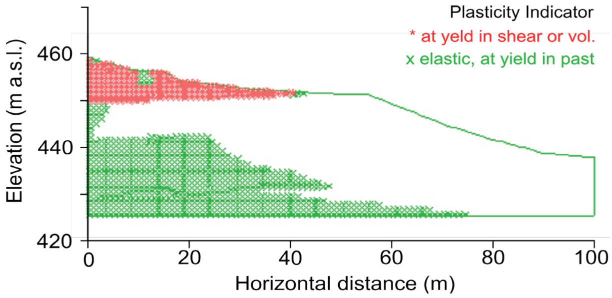

Fig. 10 - Plastic zones in seismic conditions. Only the body of the fluvio-lacustrine deposits is at yeld in shear or volume

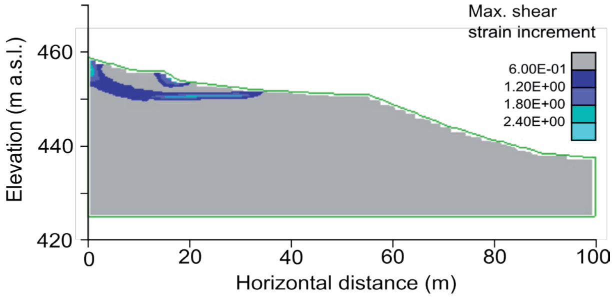

Fig. 11 - Maximum shear strain increment contours in seismic conditions, tangent to the top of the Irsina Conglomerates

highlighted by the shear strain increments magnitude, which is many orders greater than that observed under static conditions (Figure 9).

CONCLUSIVE REMARKS

Field surveys showed in a sector of the Pomarico ridge the presence of sedimentary deposits essentially different from those recognised in the stratigraphic series of the Bradanic Foredeep. Field and laboratory investigations have highlighted the substantial differences in paleontology, lithology and geomechanical characteristics.

Micropaleontological analyses indicated that these deposits are of uncertain age (Middle to Upper Pleistocene). Stratigraphically, they are later than the Irsina Conglomerates Fm. and their deposition occurred after the filling of the Bradanic basin and the emergence of the regressive paleo-surface. The presence of chalk denotes an evaporitic depositional environment in an isolated and quiet basin, as also indicated by the initial deposition of clayey sediments. From a mineralogical point of view, their composition is qualitatively similar to that of the Subapennine Clays, but with a higher amount of smectites that gives them higher liquid limit and plastic index values. The presence of montmorillonite in significant quantities, uncommon in the Subapennine Clays, could result from alteration processes and subsequent transformation from illite through mixed illite-montmorillonite layers.

The physical-mechanical characteristics of the fluvio-lacustrine deposits differ from those of the deposits of the Bradanic Foredeep succession and, in particular, from those of the Subapennine Clays, as a result of both a different tensional history and a quantitatively different mineralogical composition. In particular, the presence of significant amounts of smectites results in a significantly lower shear strength and higher compressibility values, differences that will be reflected on the behaviour of these deposits with respect to both natural and human-induced stresses. The morphological aspects of the area have in fact highlighted creep and small shallow landslides on even relatively moderate slopes.

The stability analyses, made for illustrative purposes only, showed that, assuming the mean shear strength values obtained from the laboratory tests, a stable condition is assured even in the presence of a ground water level at the highest levels reasonably possible. Taking into account the dispersion of the obtained shear strength values, the analyses were repeated considering the shear strength values, obtained by reducing the previously used average values by one standard deviation, but the stability of the entire slope was always assured. Interestingly, the value of the friction angle thus considered for the cohesive fluvio-lacustrine deposits (φ=15°) is in the range of the residual friction angle values (φ'_r= 9° - 15°) of the Subapennine Clays which have similar grain size and mineralogical composition albeit a lower montmorillonite content (Del Prete *et alii*, 1997; Fiorillo, 2004; Di Maio & Vassallo,2009).

The seismicity of the area, although not very severe, has been then considered. In this condition, always using the reduced shear strength values, the slope is no longer stable as all the fluvio-lacustrine deposits yield in shear or volume, a condition corresponding to a gradual failure mode normally not catastrophic unlike ultimate failure. Since possible seismic induced dilatancy phenomena are accentuated by low confinement stresses, these considerations could justify the observed surface deformation phenomena and the resulting small shallow landslides. It should be kept in mind that mechanical properties of surface soils, usually in unsaturated state, are significantly affected by the seasonal environment and rainfall infiltration could accelerate the slope failure before and after the creep process. Creep deformations can be then used as an indicator of incipient failure, thereby representing a threat to the safety in engineering construction.

The presence of fluvio-lacustrine deposits and their local geotechnical characterization should be then carefully specified since any even small modification of the boundary stress state could be characterised in the long term by non-negligible problems because of a critical evolution of the stability conditions of the fluvio-lcustrine levels.

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