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MICROPILES TRIPODS SHIELDS (MTS) AS UNCONVENTIONAL BREAKERS FOR THE CONTROL OF MODERATELY RAPID EARTHFLOWS (SASSI NERI LANDSLIDE, NORTHERN APENNINES)

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EXTENDED ABSTRACT

L'articolo tratta l'ideazione, la progettazione e la realizzazione di strutture non convenzionali costituite da schermi di tripodi in micropali (Micropiles Tripods Shields, MTS), finalizzate a rompere e decelerare colate di terra moderatamente rapide nella zona di transito della frana dei Sassi Neri (Val Nure, Appennino settentrionale, Provincia di Piacenza, Italia). Si tratta di una frana per scorrimento-colata di terra che ha avuto una serie di riattivazioni nel 1986, 1991, 2013 e 2014. Tali eventi sono stati caratterizzati dall'avanzamento di colate di terra moderatamente rapide nella zona di transito, che hanno poi sovrascorso il piede di frana, determinandone la riattivazione, verosimilmente per carico non drenato. Ciò ha causato un avanzamento del piede di frana ed un significativo restringimento della sezione di deflusso del torrente Nure. Pertanto, nell'ambito di lavori di consolidamento del versante successivi agli eventi alluvionali che hanno interessato la Val Nure nel 2015, che hanno previsto anche estesi interventi di rimodellamento e di ripristino della rete di drenaggio del pendio in frana, si è reso necessario sviluppare sistemi innovativi per consentire un rallentamento delle colate di terra nella zona di transito, prevenendo in tal modo fenomeni di carico non drenato del piede di frana e, con ciò, la sua mobilizzazione ed il conseguente restringimento d'alveo.

Gli schermi di tripodi in micropali (MTS) sono stati ispirati alle strutture selettive usate per le colate detritiche, agli ancoraggi flottanti ed ai "cavalli di frisia" usati in tempo di guerra. Gli elementi di base sono tripodi di micropali in acciaio di 193 mm di diametro disposti a triangolo, spinti fino al substrato roccioso e che emergono alcuni metri dal piano campagna. Ogni tripode è costituito da un palo centrale verticale (15 m di lunghezza, di cui 3,5 fuori terra) e da due pali obliqui laterali (18 m di lunghezza, di cui 3,5 fuori terra), collegati da due travi trasversali e piastre di collegamento poste nella porzione fuori terra. Più tripodi sono disposti lungo file trasversali arcuate verso monte, a formare uno schermo selettivo di tripodi contro l'avanzata delle colate di terra. La progettazione degli MTS si è basata su indagini di sito di tipo geognostico e geofisico, e la costruzione di 4 schermi MTS (costituiti da un totale di 30 tripodi) nella zona di transito della frana è avvenuta nel 2018. L'idea di sviluppare una soluzione basata sull'uso di micropali tiene in considerazione le caratteristiche dei terreni e le difficili condizioni logistiche del sito, che rendono improponibile operare in tale contesto con i pesanti macchinari necessari invece a realizzare pali di grande diametro trivellati.

Tali fattori hanno anche reso impegnative le fasi costruttive degli MTS, che hanno previsto operazioni di perforazione dei micropali entro e fuori terra, l'assemblaggio dei tripodi e la loro integrazione con gli interventi di risagomatura e drenaggio svolti nelle aree sorgente a monte dell'area di transito. In fase di completamento dell'intervento, è stato inoltre implementato un sistema di monitoraggio comprendente celle di carico (per monitorare le pressioni del terreno sui micropali), trasduttori piezoelettrici (per il monitoraggio delle pressioni interstiziali in corrispondenza dei pali), tiltmetri (per registrare le rotazioni dei tripodi) ed una stazione totale (per il monitoraggio continuo dei movimenti del versante in frana e di alcuni tripodi). In questa nota sono sinteticamente presentate e discusse le caratteristiche della frana, le valutazioni geo-ingegneristiche che hanno supportato l'ideazione e la progettazione delle strutture, le principali fasi costruttive e, infine, i risultati del monitoraggio.

ABSTRACT

The paper deals with the idea, design and implementation of unconventional one-of-a-kind Micropiles Tripods Shields (MTS) intended to break and decelerate moderately rapid earthflows surges in the track zone of the Sassi Neri landslide (Nure Valley, Northern Apennines, Province of Piacenza, Italy). The MTS are inspired to floating anchors and "chevaux de fries" used in wartime. The basic elements are tripods of 193 mm diameter steel micropiles laid out at triangle, driven into the stable bedrock and emerging some meters aboveground. Each tripod consists of a vertical upslope central pile and two lateral oblique piles, linked by two transversal beams and connection plates aboveground. Multiple tripods are spaced along transversal rows to form Micropiles Tripods Shields (MTS) to advancing earthflows. The design of MTS has been based on field investigations such as boreholes and geophysics, that indicated a limited thickness of landslide deposits in the track zone where MTS have been installed. The forces resulting from active earthflows fronts have been estimated both with geotechnical and hydraulic computations. The analysis of vertical and transversal forces as well as bending moments acting on a single tripod versus the characteristic resistances was carried out using a bi-dimensional scheme with finite-elements software Plaxis, that indicated that the stress levels were compatible with the structural resistance of the tripods. The construction of MTS took place in 2018, involving working site preparation with partial lime-treatment of the surficial layers, underground micropiles drilling and installation, aboveground micropiles welding, tripods completion with connection beams and plates. Some tripods have been instrumented with load cells for monitoring earth pressures against micropiles, electric transducers for groundwater monitoring next to the piles, tiltmeters for tripods rotations and a total station for slope and tripods movements monitoring. Results show that the acceleration of slope movements corresponds to a generalized increase of pore water pressure at all the monitored tripods and to temporary slight tilting of the tripods which has so far being fully recovered when the landside slowed down and pressure decreased. This pioneering application indicates that once the characteristics of the earthflows are carefully considered, the depth to the bedrock in the installation zone is limited, and the logistical conditions in the field during construction are adequate, the MTS can be taken into consideration as a possible unconventional solution to break down and control moderately rapid earthflows.

Keywords: *earthflows, breakers, micropiles tripods shields, Northern Apennines, Italy*

INTRODUCTION

Undrained loading is considered a significant factor in the reactivation of earthflows (Hutchinson & Bhandari, 1971). In large scale earthslides-earthflows in the northern Apennines, the reactivation of the accumulation zone can be determined by moderately rapid earthflows over thrusting toe deposits (Borgatti *et alii*, 2006; Ronchetti *et alii*, 2007; Bertolini & Pizziolo 2008; Berti *et alii*, 2017). In the Sassi Neri landslide (Nure river valley, Northern Apennines, Province of Piacenza, Italy), moderately rapid earthflows have determined, in recent years, the complete reactivation of the landslide toe, causing damages to a road, a waterpipe and a gasline, as well as a narrowing of the Nure riverbed. Therefore, breakage and deceleration of earthflows surges in the track zone can prevent the initiation of movement in the accumulation zone. While slope grading and drainage systems are common consolidation methods in this type of landslides (Mavrouli *et alii*, 2014), earthflow breakers are not, since breakers are generally only used to control debris flows or mudflows (Armanini *et alii,* 2004; Huebl & Fiebiger, 2005; Proske *et alii*, 2011). This note describes the pioneering design and application of earthflows breakers in the track zone of the Sassi Neri landslide. They are a one-of-a-kind system for which no previous state of the art reference example exists, that are functionally inspired to floating anchors and "chevaux de fries" used in wartime. Substantially, the Micropiles Tripods Shields (MTS) consist of a number of micropiles tripods spaced at regular intervals along transversal arched rows, that are meant to break and decelerate advancing earthflows. Each tripod is made of three 193 mm diameter steel piles laid out at triangle, that are driven into the stable bedrock and emerge some meters aboveground. A total of 4 MTSs (for 30 tripods altogether) have been built in the track zone of the Sassi Neri landslide in 2018 in the frame of a general slope consolidation project that included, also, slope grading and drainage systems. The MTSs have been finalized with a monitoring system comprising load cells for measuring earth pressures against the micropiles, electric transducers for pore water pressure monitoring next to the piles, tiltmeters for tripods rotations and a total station for slope and tripods movements monitoring. In this paper, the characteristics of the landslide, the engineering-geological assessments supporting the concept and design of these structures, the construction phases and, finally, the monitoring system characteristics and results, are presented and discussed.

CHARACTERISTICS AND EVOLUTION OF THE "SASSI NERI" LANDSLIDE

The Sassi Neri landslide is a complex earthslide-earthflow located close to the village of Farini (Nure river valley, Northern Apennines, Province of Piacenza, Italy) (Fig. 1). The landslide extends for approximately 10 hectares from 640 to 435 m elevation, with a maximum length of 850 m, a width from 200 to 30 m, a depth ranging from 5 to 20 m and an estimated volume of approximately 1 Mm3. It involves weak rock masses of the "Pietra Parcellara Complex" (CPP, i.e. block in matrix shales

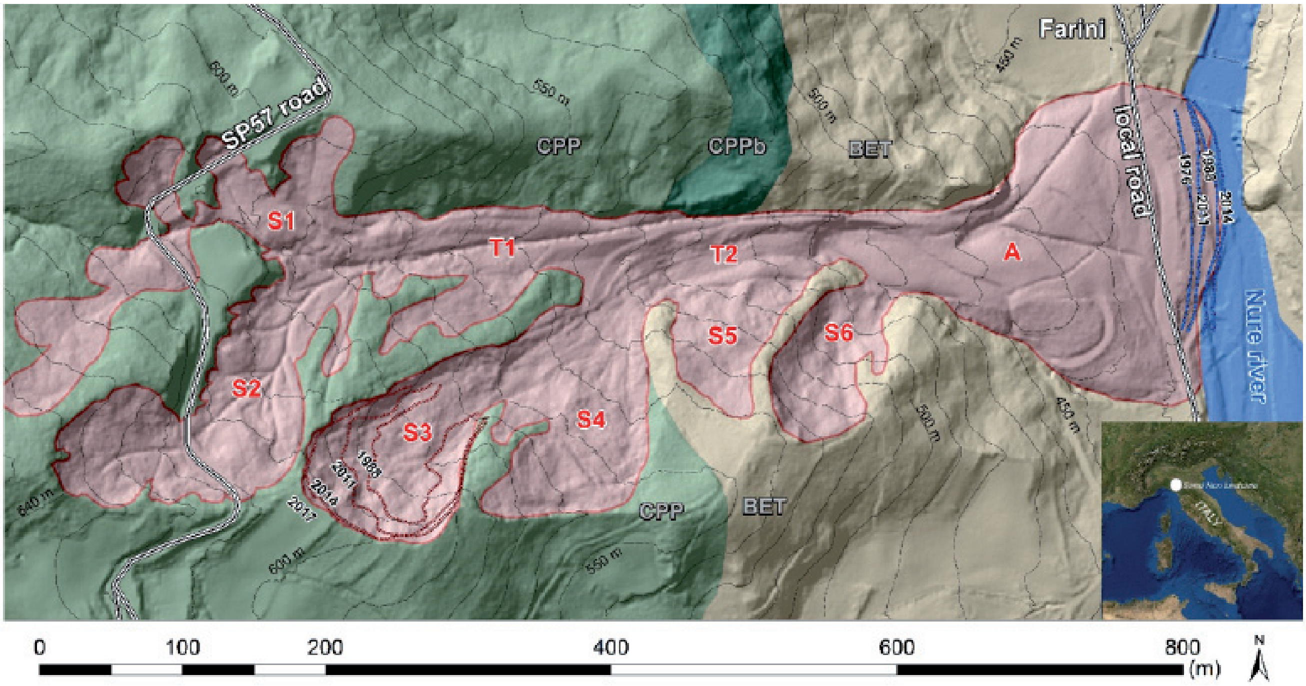

Fig. 1 – *Location and geological-geomorphological setting of the Sassi Neri landslide (Lat. 44°42'23"N; Long. 9°33'53"E). LEGEND: S1 to S6: source areas; T1 and T2: upper and lower track zone; A: accumulation zone; CPP: Pietra Parcellara Complex; CPPb: polygenic breccias; BET: Bettola Flysch. SP57: Province road. The landslide outline, the shaded relief and the contours are based on Lidar data of 2017. The dotted red lines indicate the upper limit of S3 in 1988, 2011, 2014. The dotted blue lines indicate the position of the landslide toe A in 1976, 1988, 2011, 2014*

with calcareous or siliciclastic turbidites, and, locally, CPPb, i.e. polygenic breccias in clayey matrix with basalts and serpentine clasts, Upper Cretaceous) and of the "Bettola Flysch" (BET – alternating marls, calcareous turbidites and thin shales strata, Upper Campanian to Paleocene). The local toponym of Sassi Neri (i.e. "black stones") derives by the presence of very large ophiolitic blocks from the CCP, transported downslope by slope movements that are emerging clearly in the Nure riverbed. The area is included into the Geological Map of Italy at 1:50.000 scale Sheet n° 197 "Bobbio" (Servizio Geologico D'Italia, 1997) and into Sismogenetic Zone n° 911 "Tortona – Bobbio" (Meletti *et alii*, 2004). The Sassi Neri landslide deposits are inorganic clays of medium plasticity (CM, according to USCG classification) mixed to chaotically distributed calcareous or siliciclastic gravels to blocks. On a geomorphologic basis, the landslide is made up by several source areas mostly involving CPP substratum (S1 to S6, in Fig.1), an upper and lower track zone at the transition from CPP and BET (T1 and T2, in Fig.1) and a fan-shaped accumulation zone deposited over BET substratum (A, in Fig. 1). In the last decades, as shown by multitemporal aerial images, some source areas have been substantially inactive (S5 and S6), some have been progressively stabilized (i.e. S1 and S2 after 1991) and others have suffered a significant retrogressive evolution (S3 and S4, with S3 in particular that retroceded 50 m from 1988 to 2017, see Fig. 1b). At the same time, the landslide accumulation has alternated phase of advancement (related to overall reactivation events) and phases of progressive erosion by the Nure river (related to prolonged phases of dormancy of the landslide).

Overall reactivations of the Sassi Neri landslide are known to have occurred in February 1986 (involving S1, S2, T1, T2, A), April 1991 (involving S1, S2, T1, T2, A), March-April 2013 (involving S3, T2, A), January 2014 (involving S3, T2, A). Moreover, in May 2018, one last significant partial reactivation event has been observed (involving S3, S4 and T2). The overall reactivation events in 1986, 1991, 2013 and 2014, as well as the partial one in 2018, have occurred after accumulated rainfall reaching 210 to 280 mm in the antecedent 60 days (Fig. 2a). Such rainfall amount roughly corresponds to 25 to 33 % of the annual rainfall average of 840 mm/year in the 1986 to 2020 period (in which the annual minimum has been 384,4 mm in 1988 and the maximum 1484 mm in 2014). Unlike other landslides along the Nure river that during recent events have uplifted the riverbed (Mulas *et alii,* 2018), the reactivation of the accumulation zone of the Sassi Neri landslide in the listed known events has simply resulted in an advancement of the landslide toe into the Nure riverbed. Analysis of multitemporal aerial images shows that the 1986 event (framed by 1976 and 1988 images) caused the landslide toe to advance of approximately 20 m (see Fig. 1). Later on, in 1991, the toe was artificially retroceded by excavation. Finally, the 2013 and 2014 events (framed by 2011 and 2014 images) re-advanced the toe of 20 m, reaching substantially the present position. A key common feature of the known reactivation events in 1986, 1991, 2013 and 2014, is that the mobilization of the landslide toe has been reported to be the consequence of fluidized earthflows surges travelling along the track zone and, finally, over reaching the accumulation zone (see for instance Fig. 2b picturing the 2014 event). Therefore, to prevent landslide toe advancement, it is crucial to slow down the earthflow surges that, by over thrusting the landslide toe, can determine its reactivation by undrained loading.

CONCEPT OF EARTHFLOW BREAKERS USING MICROPILES TRIPODS SHIELDS (MTS)

The limited hydraulic section of the Nure river in correspondence to the Sassi Neri landslide has become of concern for public authorities after the flash-flood event that affected the Nure river basin in 2015. Such event caused numerous debris flows in the upper watersheds (Ciccarese *et alii*, 2016, 2020) and a multi-centennial flood along the river, that determined marked changes in the riverbed morphology (Scorpio *et alii*, 2018) and, most of all, severe damages in the village of Farini and some casualties few kilometers downstream. Locals authorities from Farini feared that the bottleneck along the Nure river due to the Sassi Neri landslide could have played a role to worsen the flash-flood discharge during the 2015 event, being a possible co-cause of the disasters suffered downstream of the landslide in the village of Farini. A numerical simulation of flood-propagation commissioned to the University of Parma by the Civil Protection of Emilia-Romagna Region has demonstrated, on the contrary, that the bottleneck created by the landslide toe determined the formation of a sort of lamination basin that had actually limited the impact of the flash-flood on the village of Farini (Mignosa *et alii*, 2015). On a geomorphic basis, the flash-flood lamination effect of the Sassi Neri landslide is also made evident by the large amount of sands deposited upstream the landslide toe and by the fact that the landslide toe itself did not suffer any significant erosion during the flash-flood event, indicating that river discharge velocity was locally limited by the water impoundment upstream the landslide. Nevertheless, the study also concluded that, in any case, further narrowing of the hydraulic section of the Nure river by the Sassi Neri landslide should be prevented in order to assure the ordinary discharge of the river.

On such premises, bearing in mind that landslide toe reactivation during past known events seems to have been determined by undrained loading due to earthflows surges, the slope consolidation intervention in the Sassi Neri landslide has been designed for two main purposes: *(i)* to prevent the further mobilization and retrogression of the landslides in the source areas, by slope grading and reconstruction of a drainage network; *(ii)* to limit the capacity of moderately-rapid earthflows to suddenly overthrust and undrained load the landslide toe, by means of earthflow breakers aimed to decelerate earthflows in the track zone.

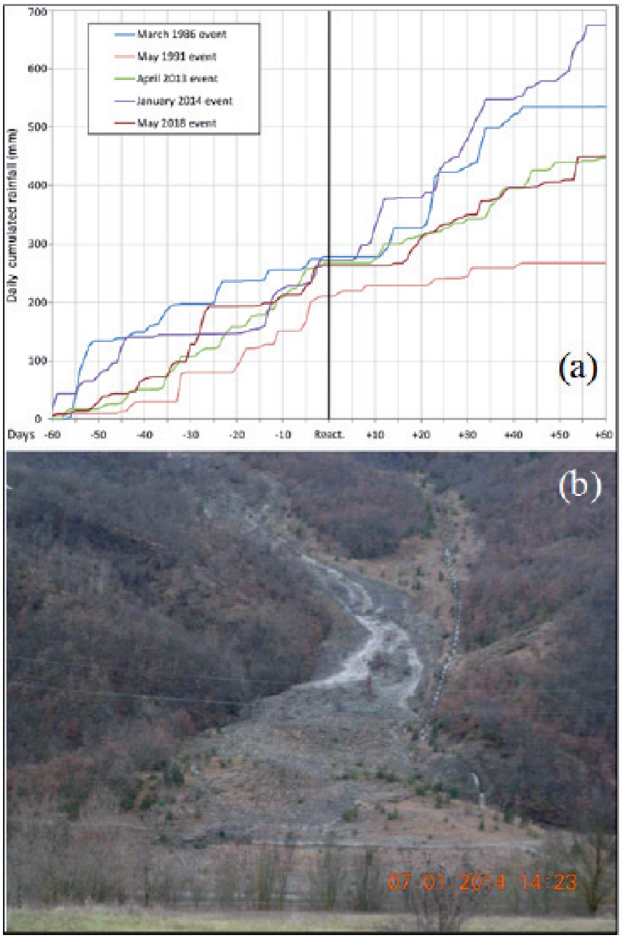

Fig. 2 – Rainfall and image of known reactivation events of the Sassi Neri landslide. LEGEND: (a) 60 days antecedent and 60 days subsequent cumulated rainfall;(b) earthflows surges over-thrusting the accumulation zone during the reactivation of January 2014

Debris flows and mudflows breakers are generally constituted by concrete or steel structures acting as slotted-dam or partial retaining structures for fluid mixtures of coarse to fine grained debris and water (Mizuyama, 2008). However, these types structures are not suitable for moderately rapid earthflows, because the width of the track zone through which an earthflow develops is not as well constrained as that of debris flows or mudflows channels and because the rheology of the materials is different, so that the narrow slots of conventional breakers would probably determine a complete blockage of the highly viscous earthflow, that in turn could rapidly accumulate and generate an overwhelming earth pressure on the structures. Consequently, breakers for earthflows must be conceived on a different basis. Some authors have recently experimented arrays of floating anchors to slow down earthflows, taking advantage of the resisting force introduced into the system by contrast plates (Bisson *et alii*, 2014). The same principle can be exploited by deploying, along a slope, an array of adequately widely spaced single structures anchored to the substratum. The array would allow the earthflows to move in between one structure and another, limiting accumulation and ensuring that in case one element of the array is buried or failed, it does not undermine the functionality of the other elements and of the entire system as well. Following such ideas, an unconventional earthflow breakers array has been designed for the Sassi Neri landslide, by lining up a number of micropiles tripod elements - sort of "chevaux de fries"- emerging some meters aboveground and driven into the underlying bedrock. Each tripod is constructed with 193 mm diameter steel-micropiles: a vertical upslope central pile and two lateral oblique piles, linked aboveground by two transversal beams and a number of connection plates. In practice, a row of tripodal elements built transversally to the earthflow direction, forms what can be simply termed a "Micropiles Tripods Shield" (MTS). The identification of a micropiles-based solution, instead of other alternatives based on large diameter piles, took into consideration the logistics of the construction site in Sassi Neri, i.e. principally the soft-soil nature of the landslide material and the steepness of the off-road access service path, that allows only relatively light drilling machinery and trucks to operate on it, thus excluding the use of heavy drilling rigs and concrete mixing trucks.

SITE-INVESTIGATION AND MTS DESIGN

The MTS design has been based on geophysical and geotechnical site-investigation. Seismic refraction tomography, boreholes, open pits sampling and laboratory analyses, have been used to determine the depth to bedrock along the landslide and to characterize landslides deposits. Geophysical surveys evidenced that inside the lower track zone (T2 in Fig. 1), at the time of survey, the thickness of existing landslide deposits (characterized by P waves velocity lower than 1200 m/s) was limited to 5 m or little more (Fig. 3). Sampling and direct shear tests have provided the residual shear strength parameters for the earthflow materials (i.e. 16° friction angle and 12 kPa coherence), that are considered representative of the mobilized resistance during earthflow surges. Groundwater in the track zone, likewise in most parts of the landslide, is considered as high as ground level. Taking advantage of the limited thickness of landslide deposits along the track-zone, the length of the micro-piles making up each tripod has been established as follows: vertical piles, 15 m total length with 3,5 m aboveground; oblique piles, 18 m total length with 4 m

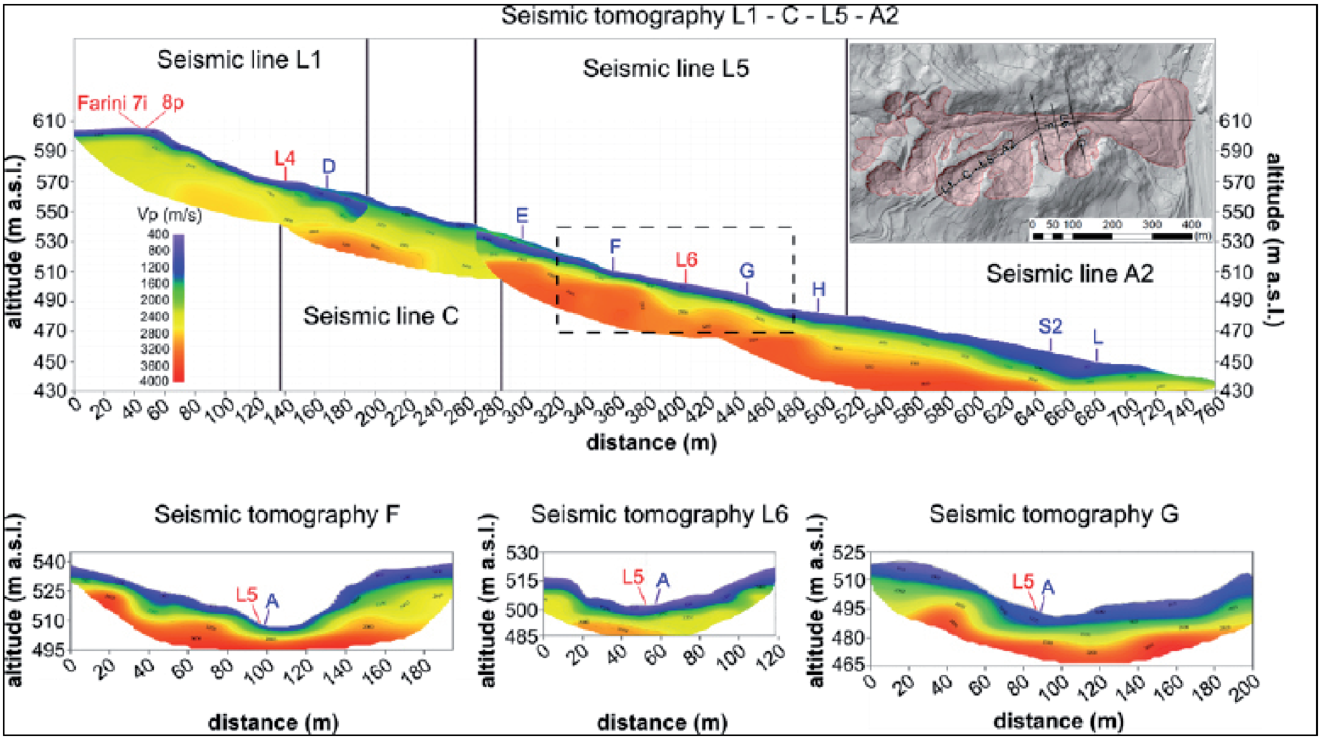

Fig. 3 – *Examples of the results of geophysical surveys (p-wave seismic refraction tomography) in the Sassi Neri landslide. LEGEND: (a) longitudinal section by combination of different lines; (b, c, d) transversal sections in the MTS construction track zone*

aboveground and 60° inclination. The interaxle distance between the piles of each tripod is 0.75 m, so a tripod results 1.5 m wide. The tripods are arrayed at 1.5 m spacing along a curved upstream row, forming a shield to advancing earthflows. In total, 4 MTS rows (each made of 9 to 6 tripods, for 30 tripods in total) have been designed in the track zone of the Sassi Neri landslide (Fig. 4).

The assessment of unfavorable forces acting on the MTS while they will be impacted by the advancing moderately rapid earthflow surges is one of the key issues in MTS design. As a matter of fact, while geotechnical approaches for the design of retaining walls or piles acting against non-moving terrains are well established, and hydrostatic, hydrodynamic and mixed approaches can be used to obtain realistic estimates of impact forces for debris flows breakers (Armanini, 1997), there are no references to be used in approaching the design of unconventional structures such as the MTS, and this determines large inevitable uncertainties. Therefore, at first, the forces acting on each pile as a result of moving earthflows have been estimated both with geotechnical and hydraulic computations. Geotechnical computations, based on residual shear strength parameters, considered alternatively a passive earth pressure conditions, and the net driving force deriving from an infinite slope analysis of a 150 m long and 3.5 high translational slide along a 15° inclined surface. The hydrostatic, hydrodynamic and mixed approaches used for debris flows where applied with the formulations and calibrated parameters listed in the review paper by Armanini, 1997 and citations therein. In all the calculations, a pile diameter of 193 mm and a height aboveground of 3.5 m were considered. Results indicated that, of all these methods, the passive earth-pressure computation returned the maximum acting force distribution. Consequently, in lack of other possible reference procedures, and being conscious of the large uncertainties associated to this computation, the passive state approach was finally selected to determine the characteristic values of unfavorable permanent actions to be used to verify the tripods against ultimate states. The passive earth pressure approach was also extended under present-days ground surface, in order to account for forces deriving from the potential remobilization of the existing landslide deposits once they are over thrusted by the surficial rapidly advancing earthflows. At the same time, the characteristic resistances of the micropiles were determined according to UNI-EN-10025-2 considering steel type S355 (Fe510). The analysis of vertical and transversal forces as well as bending moments acting on a single tripod versus the characteristic resistances, was carried out using a bi-dimensional scheme with finite-elements software Plaxis. In the bi-dimensional analysis, the vertical pile of the tripod has been simulated as a stand-alone plate element, while the two oblique piles have been simulated as a single plate element in which double actions and double resistances apply. The vertical and oblique plate elements have been constrained to translation and rotation at their intersection, to simulate the designed connection between micropiles. The analysis has considered two scenarios: passive forces due only to surficial earthflows of 3.5 m thickness; passive forces due, also, to the mobilization of existing over thrusted landslide deposits, thus with passive earth pressures extending to 5 m depth from present-day ground surface. Results showed that in both scenarios, the axial and transversal stresses acting on the micropiles are lower than the maximum admissible

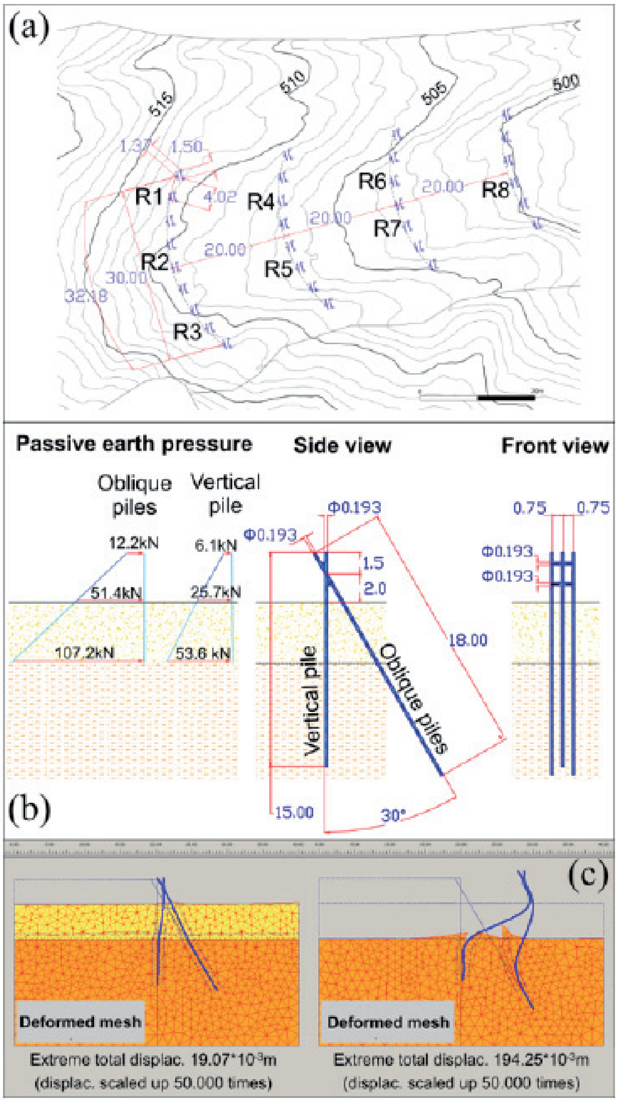

Fig. 4 – Design schemes of the MTS and analysis results. LEGEND: (a) Planimetric layout of the MTS (labels R1 to R8 refer to monitored tripods, see data in figure 7). (b) Design sections with details of micropiles dimensions and passive earth pressure distribution considered in the analysis. (c) sample images referring to the deformation of the micropiles in case of passive earth pressure generated by movements of surficial 3.5m thick earthflows or by, also, reactivation of existing landslide deposits down to 5m depth

Fig. 5 – Field views of the main MTS construction phases. LEGEND: (a) working site preparation with lime-treatment of the surficial layer of the embankments. (b) underground micropiles drilling and installation; (c) aboveground micropiles welding; (d) tripods completed with connection beams and plates

yield strength, while the flexural stresses can be slightly higher than the admissible plastic moments in case of passive forces due, also, to the mobilization of existing over thrusted landslide deposits.

CONSTRUCTION AND MONITORING OF MTS

The construction of MTS in the Sassi Neri landslide has been carried out from July to December 2018 in four main phases: working site preparation; underground micropiles installation; aboveground micropiles tripods completion; ground reshaping and finalization.

The working site preparation phase could not start earlier than late July 2018 since the lower track zone of the landslide, inside which the designed MTS had to be constructed, was affected by the propagation of an earthflow during May to June 2018, depositing 2 to 3 meters of very low consistency fully saturated clayey deposits. Consequently, in order to avoid the micropiles drilling machine to sink into the soil while drilling, thus loosing verticality, the working site has been prepared by partial removal of the recent earthflow deposits, so to create horizontal embankments, and by lime-treatment of the surficial layer of embankments (Fig. 5a) Finally, at the drilling points, large limestone blocks selected from the earthflow deposit have been rolled out. The underground micropiles drilling and installation phase started in early August 2018, by first drilling and installing all vertical piles and then all the oblique piles (Fig. 5b). Due to the additional deposit left by the earthflows of May to June 2018, bedrock was reached by the piles at depths varying between 8 to 12 m, hence slightly deeper than considered in the design phase. In order to increase the strength of the micropiles, the standard threaded coupling junction system was substituted by a one meter long inner pipe for bayonet coupling between casings and micropiles have been fully grouted. This phase was completed by late September 2018.The aboveground micropiles tripods completion phase was carried out throughout October 2018. Bayonet coupling between micropiles casings was used and reinforced by welding of all the junctions (Fig. 5c). Once the micropiles were completed, they were connected by using, for each tripod, two transversal pile elements and twelve opposing steel plates (2 cm thick and 40x40 cm large) connected, two by two, with four M32 thread bars (Fig. 5d). By early November 2018, all the 30 micropiles tripods making up the 4 Micropile Tripods Shields were fully assembled, coated with anti-rust paint and completed (Fig. 6a and 6b). Due to practical constrains during construction, the downslope spacing between MTS rows resulted higher and more irregular than designed, i.e. 20 m between the 1st-2nd MTS rows (numbered from upslope) and 40 m between the

Fig. 6 – Field and aerial views of ground reshaping and MTS finalization as integral part of all other slope consolidation intervention. LEGEND: (a) Upslope to downslope field view. (b) Upslope to downslope aerial view. (c) Downslope to upslope aerial view with labels and relative position of monitored tripods (R1 to R8) and topographic monitoring prisms (SN13 to SN19)

Fig. 7 – Details of the monitored tripods. LEGEND:(a) Layout of devices in the front-vertical piles: two load cells (one aboveground and another underground) and a pore-water pressure transducer (inserted into a sand pocket). (b) detail of the aboveground load cell (range 0-2000 kg, loaded via a 25×15 cm contrast plate). (c) detail of underground load cells (range 0-2000 kg, loaded via a 25×15 cm contrast plate visible in box a) and pore-pressure transducers (range 0-100 kPa). (d) Tiltmeter placed on top of the central pile (bi-axial), wireless datalogger (upper part of central pile) and topographic reflector prism (in the oblique pile)

2nd-3rd and 3rd-4th. MTS rows. The final ground reshaping phase took the whole month of November 2018 to be completed. In practice, was the finalization of the slope grading and reshaping activities conducted in the upper part of the slope, during the previous months, in parallel to the MTS construction (Fig. 6c). Ground reshaping in the MTS zone has allowed a general gentle concavity to be created, so that advancing future earthflows would point to the center of MTS rather than divert laterally. Finally, side levees and surface water discharge ditches, integrating the drainage system in the source area, were created to finalize the job together with hydroseeding.

After construction, 8 tripods have also been instrumented for monitoring in an automated wireless sensor network (see location in Fig. 4a and Fig.6c). In each tripod, the following sensors are installed (Fig. 7): 1 load-cell one and half meter underground (meant to measure earth pressure on existing landslide deposits in the range 0-2000 kg, loaded via a 25×15 cm contrast plate); 1 load cell one meter aboveground (meant to measure earth pressure from future earthflow surges in the range 0-2000 kg, loaded via a 25×15 cm contrast plate); 1 pore pressure transducer in a sand pocket two meters underground (meant to measure groundwater pressure in the range 0-100 kPa,); 1 biaxial tiltmeter in the upper part of the tripod (meant to measure longitudinal and transversal tilting of tripods in the range ±30°). Moreover, topographic prisms have been installed in 4 tripods (i.e. one for each MTS row) and along the slope so that, similarly to other case studies (Corsini *et alii*, 2015), the landslide and the MTS movements could be monitored on a continuous basis with a robotic total station performing polar surveys from the opposite slope.

Monitoring time-series from December 2018 to October 2020 (Fig. 8) show a good correlation between the parameters measured at the tripods and landslide movements recorded on topographic prisms located immediately upslope the MTS. In particular, in two periods (02/04/2019-02/06/2019 and 20/10/2019-28/12/2019), the acceleration of slope movements corresponds to a generalized increase of pore water pressure in all the monitored tripods. At the same time, in the first of these periods, a temporary slight tilt of the tripods was also recorded, which was fully recovered when the landside slowed down and pore pressure decreased. It should be pinpointed that total station data show that the tripods did not record any significant movements prior or after tilting, so that the recovery of tilting must be ascribed to an elastic return of tripods to the initial verticality. The fact that no tilting of tripods was observed in the first period of landslide movements can perhaps be ascribed to the fact that reshaping of the slope left deposits quite loose, so that it required some times and movements before deposits could determine significant pressure on tripods. Actually, as regards earth pressure on tripods, data from the majority of load cells placed underground (the only one to be considered, as no earthflows surge has yet impacted on cells installed aboveground) show relatively constant values throughout the whole monitoring period, with values in the order of 150 to 350 kg. Considering a load plate of 375 cm^2 (i.e. 25×15 cm) such load would correspond to horizontal earth stresses lower than 100 kPa, compatible with the horizontal passive earth pressure condition considered for design. However, two cells (R3 and R8) recorded significantly higher load values, that progressively increased during the monitoring period until exceeding measuring range. The interpretation of this behavior is not straightforward, since other load cells right next to them did not show such trend. It can be tentatively supposed that data of these two load cells are biased by the presence of large rock blocks acting on them, thus integrating horizontal earth stresses over a much larger surface than that of the contrast plates of load cells.

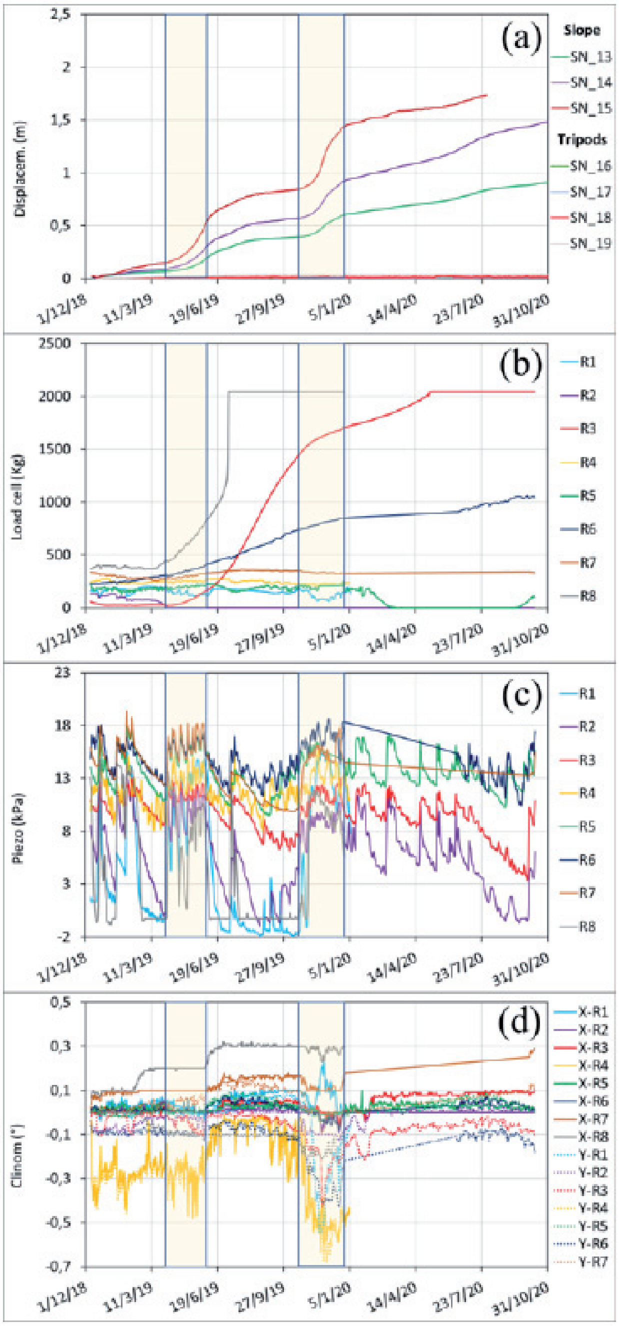

Fig. 8 – Monitoring results. LEGEND:(a) Displacement recorded by total station for selected topographic prisms immediately upslope the MTS and on the tripods; (b) tripods load cells data; (c) tripods pore-pressure transducer data; (d) tripods tiltmeters data. The position of topographic prisms (SN) and monitored tripods (R) is indicated in figure 5c

DISCUSSION AND CONCLUSIONS

The MTS earthflows breakers implemented in the Sassi Neri landslide are intended to slow down surficial earthflow surges moving at moderately rapid velocities along the track zone that, in the past, by reaching and over-thrusting the landslide toe have reactivated it by undrained loading. Since no earthflow surges have occurred after MTS construction, and because they are the first of their kind and no previous experience can be used for reference, the real efficiency of the MTS cannot be assessed yet. Nevertheless, comments can be made regarding the factors constraining the applicability of this kind of nonconventional structures in other case studies. One main factor of constrain and of potential uncertainty is that the earthflow surges must be sufficiently fluidized to be effectively broken apart and slowed down by this kind of structures. The conditions leading to transition from plastic to a fluid state of earthflows have been recently analyzed on the basis of sudden drops of shear-wave velocity propagation, and it seems to occur in earthflows moving at velocities higher than m/day (Berti *et alii*, 2019, and citations therein). Furthermore, the earth flow surges must have a thickness limited to a few meters, not only for the limits arising from increasing earth pressures, but also for practical reasons related to the limited aboveground extension that this kind of structures can have. Another issue is the need to drill the micropiles into bedrock for an adequate depth, which implies operating on areas with limited deposit thickness. During the design phase, almost half of the pile was considered to be extending into bedrock. However, during construction, the landslide deposits thickness resulted higher than expected, both due to earthflows occurred between design and implementation phases and, also, because refraction seismic surveys in the design phases were unable to fully picture the lateral variability of deposit thickness. Finally, the logistical conditions in the field during construction should also be carefully considered.

Access to the area must be assured at least to medium-weight drilling and operating machineries, and this can be complex in many cases. All that considered, it can be concluded that the micropiles tripods shields (MTS) presented in this note can be taken into consideration as a possible unconventional solution to break down and control moderately rapid earthflows only after the specific conditions in the landslide site of interest are carefully evaluated.

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