Remediation of The Pissouri Landslide in Cyprus

Argyris Alexandris, *Archirodon NV, Athens, Greece, (form. OTM SA); email:* a.alexandris@archirodon.net,
Irini Katsipi Griva, *OTM SA, Athens, Greece; email:* otmate@otenet.gr
Maria Abarioti, *OTM SA, Athens, Greece; email:* otmate@otenet.gr

ABSTRACT: *During the winter of 2001-2002, a landslide of 80.000 m^3 was activated and moved downslope at the Northeast outskirts of the Pissouri village in Cyprus (Limassol prefecture), displacing a section of a country road that was crossing the upper part of the sliding mass and destroying three newly built residences. This paper presents the geologic and hydrogeologic regime of the landslide and its implication on the landslide's mobilization. Geotechnical site investigation and post failure monitoring, in conjunction with slope stability back analysis formed the basis for the study of the slide and subsequently guided the remediation strategy. Various possible interventions to stabilize the slope and allow the safe reconstruction of the displaced road have been investigated and compared considering both economic and environmental criteria. The performance of the remediation measures has been studied in terms of stability safety, using numerical models previously calibrated via back analyses. Observations made during the execution of the stabilization works provided additional data verifying and supplementing the original design.*

KEYWORDS: Landslide remediation, hydrogeologic regime, Nicosia formation, weathered marl.

SITE LOCATION: IJGCH-database.kmz (requires Google Earth)

INTRODUCTION

Landslides in the Western and Southwestern part of the island of Cyprus are a constant threat for built up areas and existing or new civil infrastructure (roads, bridges etc). Landslides in Cyprus involve geological formations of weak calcareous or argillaceous rocks and rock-soil mixtures, of complex and sometimes chaotic structure. Weathering of weak rocks, quickly result in the formation of stiff clayey soil or soil-rock assemblies, which have a strong tendency to slide. In the Paphos prefecture, these phenomena are more frequent, due to the presence of geological formations prone to landsliding, like the Mamonia mélange and the Kannaviou bentonitic clays. Various researchers have studied these formations in the context of several failures observed in natural and cut slopes (Pantazis 1969, Northmore et. al., 1988, Charalambous and Petrides 1997, Hart et al. 2010) and highlighted the significance of landside hazards in the western part of the island of Cyprus. In the Limassol prefecture (southwestern Cyprus) landslides occur less frequently, mainly due to the absence of the aforementioned formations. However, in certain geological formations, found in the Limassol prefecture, under adverse morphological and hydrogeological conditions, landslides do occur, can be equally hazardous, and their remediation is proven to be very costly in most cases. A medium size landslide, which affected the village of Pissouri, is a typical example of instability in weathered Neogene deposits which cover the southwestern coast of Cyprus. This case is presented herewith, in order to highlight the prevailing causative factors of such incidents, to discuss the remediation strategy and analyze the performance of the stabilization measures.

The Pissouri Landslide

The village of Pissouri is located close to the southwestern shore of the island of Cyprus and is situated on a relatively flat hilltop, 200 m above sea level. Touristic development led to the gradual expansion of the built area down the crest of the slopes surrounding the hill. During the winter of 2001-2002, after a period of sustained precipitation, at the North East side

Submitted: 15 May 2015; Published: 16 December 2016
Reference: Alexandris, A., Griva, I.K. and Abarioti, M. (2016). *Remediation of The Pissouri Landslide in Cyprus*. International Journal of Geoengineering Case histories, Vol.4, Issue 1, p.14-28. doi: 10.4417/IJGCH-04-01-02

of the build-up area, approximately 80.000 m^3 of ground mobilized and moved 0.5 m to 1.0 m downslope. The landslide distorted a section of a country road which was crossing the upper part of the slide and three residential buildings built adjacent to it. It continued to move the following years, at low rates during the dry seasons and at an accelerating rate during the wet seasons. With an average movement rate of 3 cm per month the landslide displacement accumulated up to 3.00 m – 3.50 m during the next 10 years. The landslip was immediately followed by water springing at the toe of the sliding mass, and continued the following years to seasonally gush out water and mud, pinpointing the significance of groundwater seepage through the sliding mass to its mobilization. An aerial view of the landslide, the distorted road and the damaged buildings is presented in figure 1, which can also be seen on the photographs of figure 2.

Figure 1. Aerial view of the Pissouri landslide. Dashed line indicates the border of the sliding mass. Notice the distorted road and the damaged residential buildings resting on the sliding mass.

Figure 2. Left: Northward view of the Pissouri landslide. Dashed line marks the border of the sliding mass. Back scarp is also marked. Right: The distorted road and damaged buildings resting at the upper part of the sliding mass.

REGIONAL GEOLOGY AND CLIMATE

The Pissouri area is covered by sediments of Pliocene-Pleistocene age, most notably calcarenites, carbonate marls and sandstones of the Nikosia formation. The sandstones are younger, of Pleistocene age and form the higher ground over most of the Pissouri area. They are intercalated with widespread red color paleosols and conglomerates and in most sites are covered by a sandy layer of weathered sandstone. Underneath lies the Pissouri marl, a gray stiff to hard calcareous marlstone of Pliocene age, which is characterized by occasional sandy interlayers. The marlstone is prone to fast weathering and in most sites the fresh marl is covered by a layer of weathered marl which is encountered as an intensively fractured reddish - brown rock which in places disintegrates into a compound of marl blocks within a matrix of stiff fissured silty/clayey soil. The regional distribution of the aforementioned sedimentary units is depicted in Figure 3 (after Stow et al., 1995). The location of the landslide is also noted on the map.

The climate in Cyprus is Subtropical-Mediterranean and Semi-arid, with very mild winters and warm to hot dry summers. A distinctive feature of the island's climate is the increase in annual rainfall from 300 mm along the coast, to nearly 1200 mm at the Troodos mountain. Rainfall events occur in Cyprus mainly during the winter, between November and March. The average precipitation from December to February accounts for about 60 % of the average annual total, and that between November to March is usually about 80 % of total. Variability in annual rainfall is characteristic of the island, with frequent and sometimes severe droughts and exceptionally wet seasons. Prolonged wet seasons and intense rainfall events are associated with a temporary increase in the occurrence of landslide events in the island, as reported by Pantazis (1969), by Northmore et al. (1988) as well as by Hart and Hearn (2013) among others.

In the Limassol prefecture in particular, the annual precipitation is low, averaging 300-400 mm per year. The monthly rainfall time series retrieved by the Pissouri meteorological station during the 1998-2008 decade is presented in Figure 4. It is observed that during the December of 2001, when the Pissouri landslide was mobilized, precipitation was indeed high, exceeding 230 mm, but not a unique event in the decade. High precipitation undoubtedly triggered the landslide, but the contribution of other factors to slope instability should also be investigated. The high precipitation of December 2001 is associated with subsequent landslide events that took place in other parts of the island, as reported by Hadjigeorgiou et al., (2006) and Kyriakou & Hadjigeorgiou (2008).

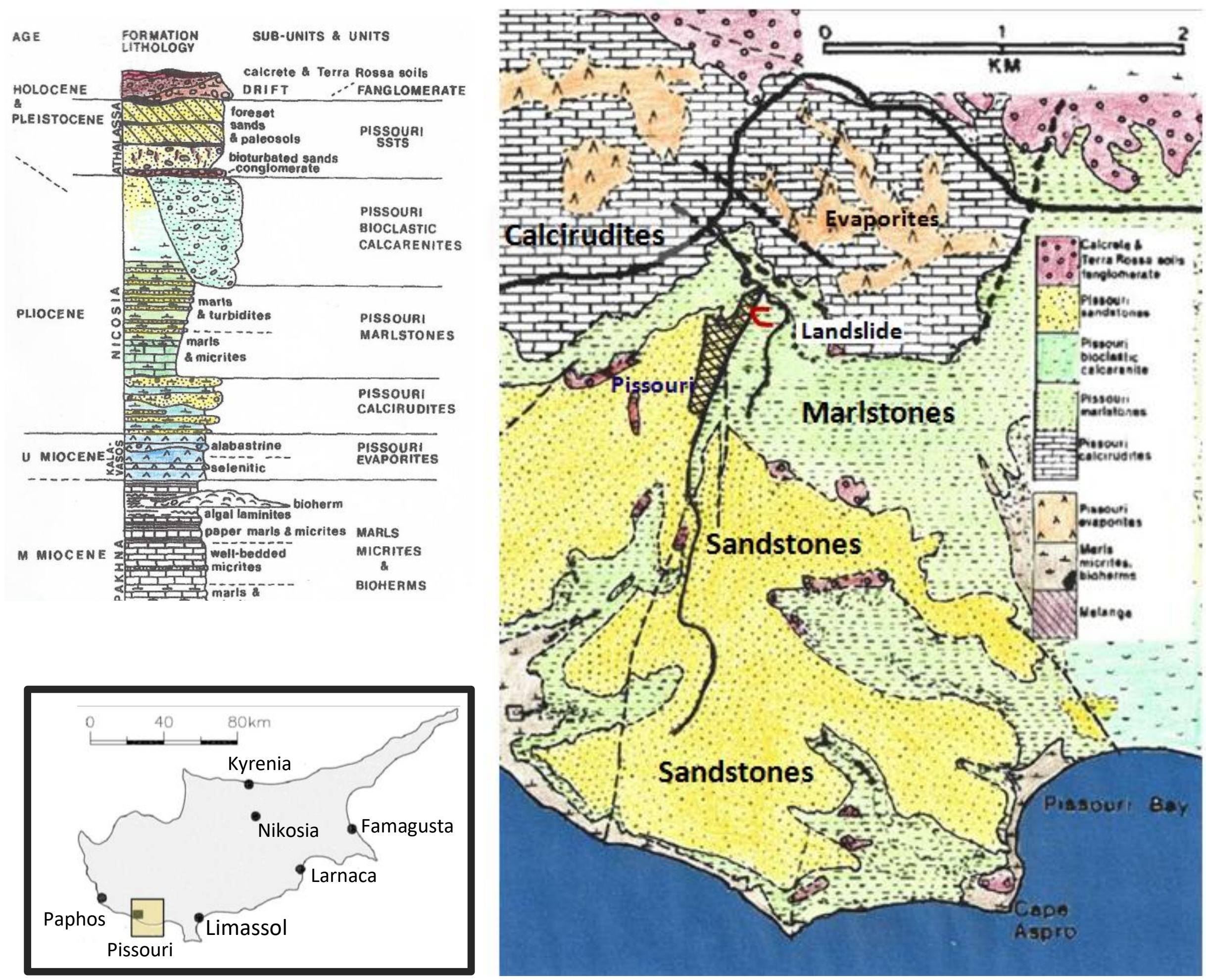

Figure 3. Regional Geology of the Pissouri area. The village is developed on sandstones (yellow) underlain by the Pissouri marls (olive green). Geology after Stow et al., (1995)

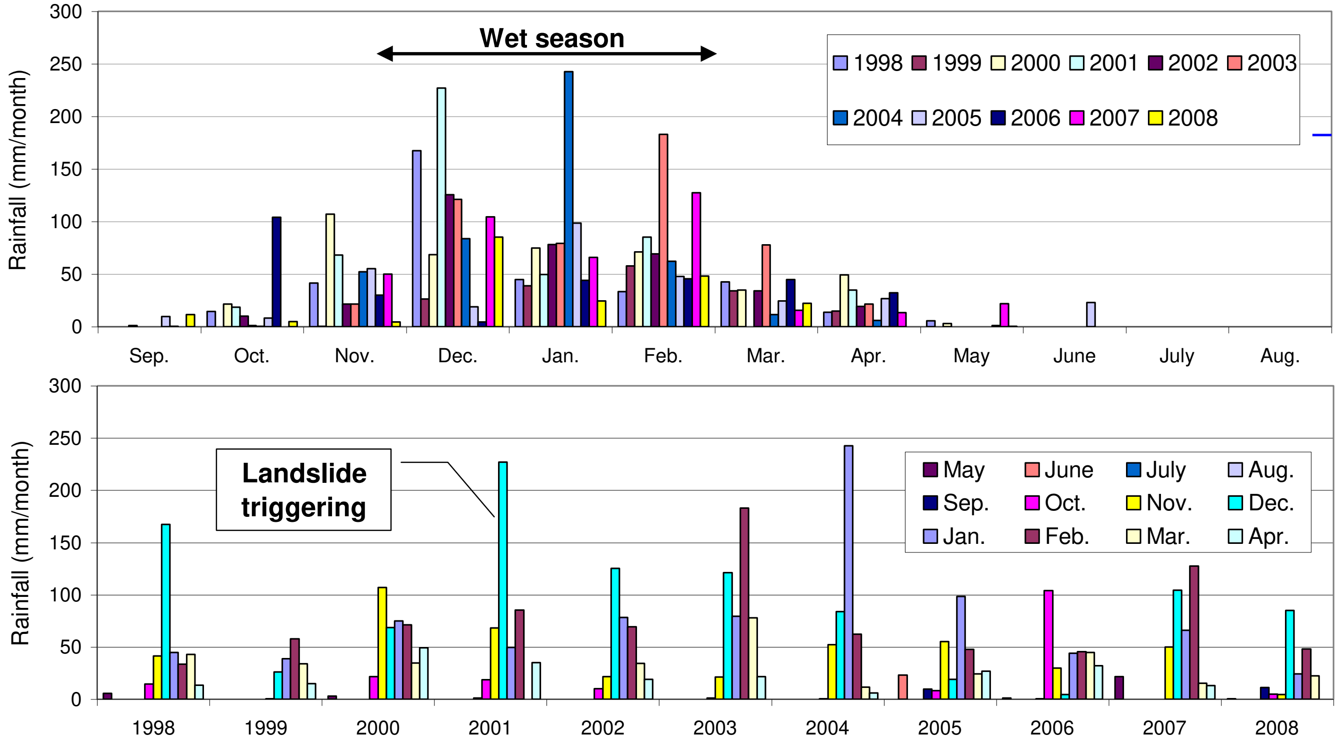

Figure 4 Seasonal (upper figure) and annual (lower figure) distribution of monthly precipitation for the decade 1998 ~ 2008. Data from the "Pissouri" meteorological station.

SITE CHARACTERISATION

During various geotechnical site investigation campaigns, conducted after the landsliding, more than 8 boreholes were drilled in the sliding mass (a couple of them inclined) to retrieve soil samples for inspection, characterization and laboratory testing. Most of them have been performed by the Geological Survey of Cyprus and a few by local contractors. In many cases, short lived piezometers were installed after drilling and were monitored until the landslide movement sheared off the piezometer tubes. For the location of the sliding surface three inclinometer tubes were installed and monitored for a period of four months, which helped to reliably identify the slip surface. Figure 5 depicts the location of some of the exploratory boreholes on a simplified geotechnical section of the landslide area. The location and response of the inclinometers alongside the postulated slip surface are also shown in figure 5.

The bedrock is a low strength yellowish calcareous marlstone (UCS≈10 MPa), fairly undisturbed, but marked by a medium to thick bedding (l0 - 100 cm) dipping with a low angle to south-southeast. Stress relief lead to the development of sub-verical joints and fissures and water circulation gradually resulted to the development of a capping weathered crust. Weathering is associated with oxidization and decalcification of the marlstone, the gradual increase in pore volume (further promoting seepage) and subsequent intact strength degradation to that of a stiff soil. In the landslide site the thickness of the weathered marl crust is 5 to 10 meters and the material was encountered in places disturbed and sheared by the landslide movement. The succesion of sound and weathered marl is depicted on the photograph of Figure 6, where the weathered material is noted by the distinct brownish color and its intense fissility. Soil samples obtained from the weathered zone are classified as CH-MH with a plasticity index (PI) ranging from 20% to 35% and clay fraction (CF) between 30% and 60%. Natural water content of the weathered marl does not exceed 30% and the material is generally stiff with SPT values ranging from 25 blows/ft to refusal. Typical classification test results from this zone are also presented in Figure 6.

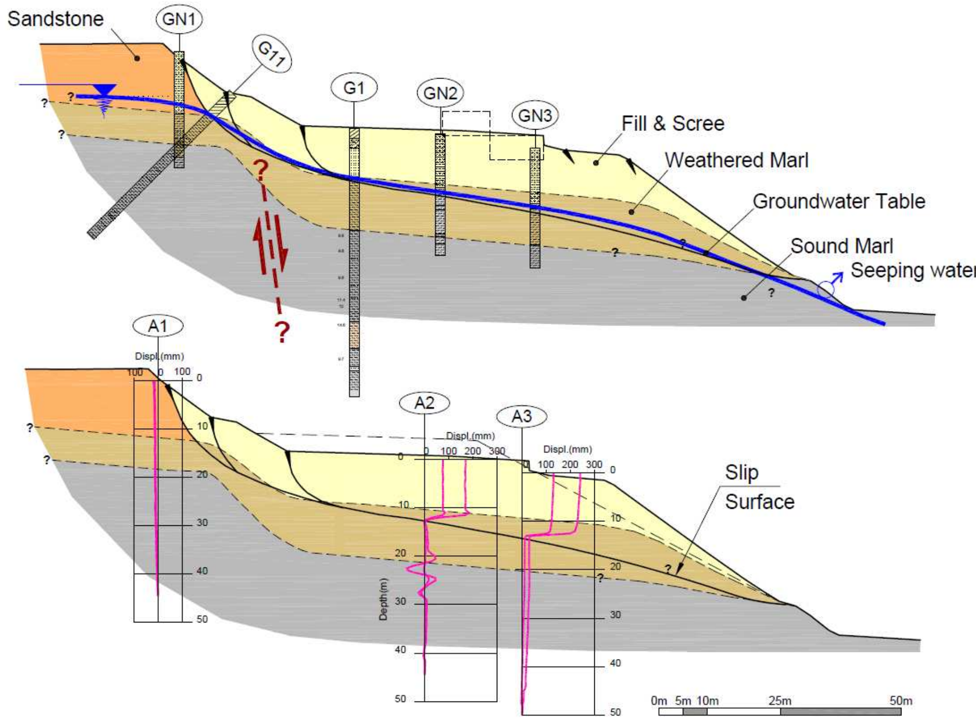

Figure 5. Geotechnical section along the sliding mass. Top: Exploratory boreholes Stratigraphy and ground water table Bottom: Inclinometer readings and location of slip surface.

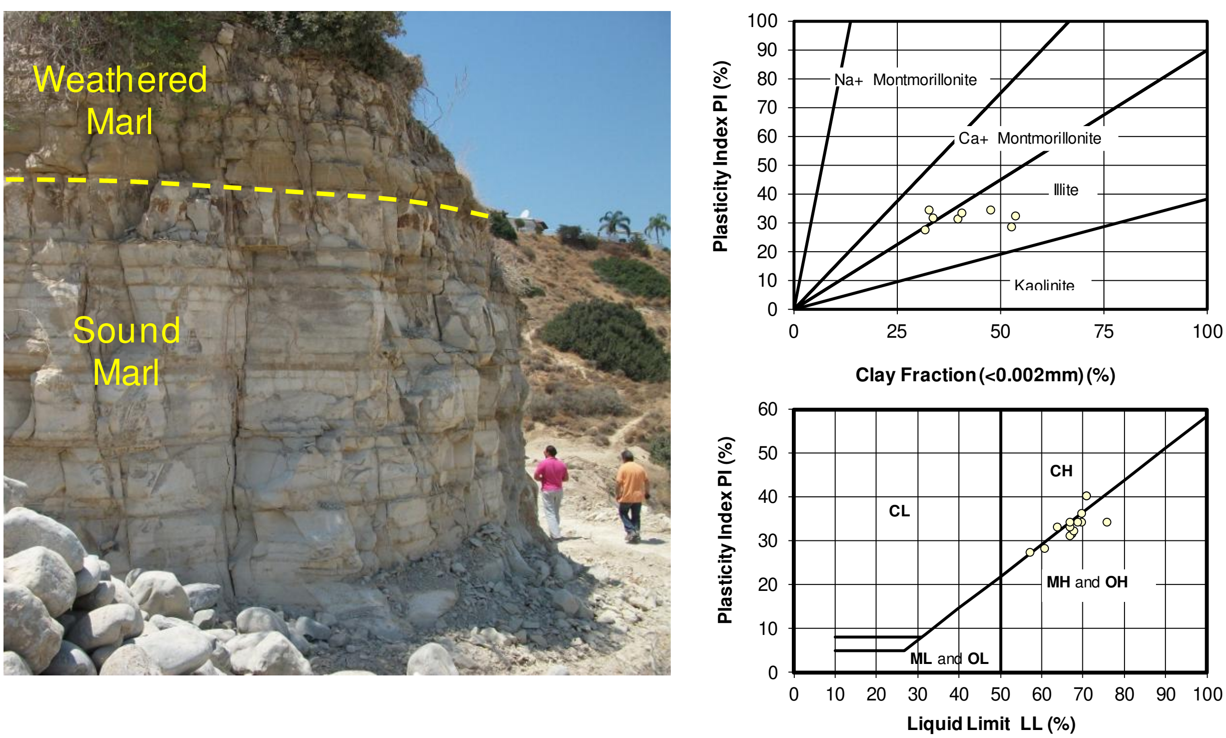

Figure 6. Left: Typical appearance of the bedded calcareous marl and the overlying weathered crust. Right: Typical soil classification test results performed on samples retrieved from the weathered marl zone.

The upper part of the landslide was found to be covered by mixed materials (sand, gravels and red clays) of natural scree, as well as man made fill and rubble. This stratum, in places up to 10 m thick, was formed gradually by material accumulating from the degrading upslope area, as well as by fill placed more recently during the construction of the road and later for grading the land plots where the three residential houses have been constructed. The additional weight of these materials was considered from the first steps of this investigation as a significant contributing factor to slope destabilization.

The capping sandstone layer of the marlstone series was encountered at higher elevations (see Figure 5), by the boreholes drilled beyond the back scarp of the landslide, and it seems that this more competent unit eventually prevented the retrogression of the landslide further upslope. The presence of the capping sandstone unit upslope controls also the hydrogeological regime of the slope, since it is the main water bearing stratum which steadily convey groundwater to the slope, as will be demonstrated in the following chapter.

The slip surface was located by combining the monitoring data from the two inclinometer tubes (A2 & A3) installed within the sliding mass and the careful mapping of slope breaks and cracks, visible on the ground (in some cases), on the cracked pavement of the distorted road, the houses and the paved ground around them. The third inclinometer tube which had been installed further upslope did not show signs of movement (as shown in figure 5) and allowed the identification of the back scarp of the slide with confidence.

The shear strength parameters of the weathered marl, where the slip surface eventually developed, was investigated in the laboratory by means of a few slow (drained) shear box tests, which averaged to c'=30 kPa and φ'=21º as shown in figure 7. Residual shear strength parameters, were obtained from ring shear tests (Broamhead ring shear apparatus) which yielded values of c_r'=0 and $φ_r$'=21º. The values of the residual angle of shearing resistance determined directly by the ring shear tests are compared with the dataset presented by Skempton (1985) (Figure 8) and are found to be in the upper bound of the scatter. This is probably due to the fact that the particular ring shear tests were carried out on fairly silty samples (classified as MH) and not on clayey ones.

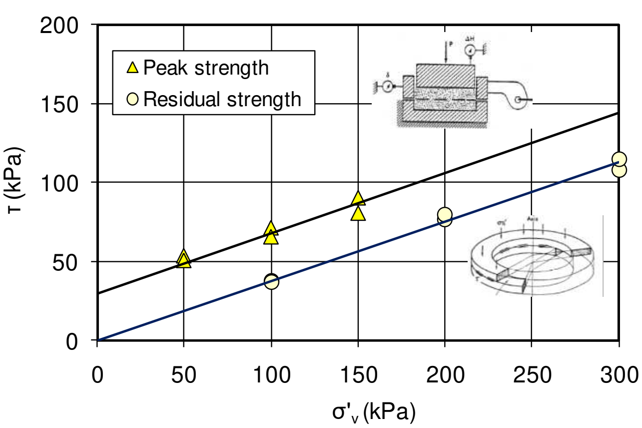

Figure 7. Shear box and ring shear test results on soil samples from the weathered marl horizon. Peak strength c'=30 kPa, φ'=21º. Residual strength c_r'=0 kPa $φ_r$'=21º.

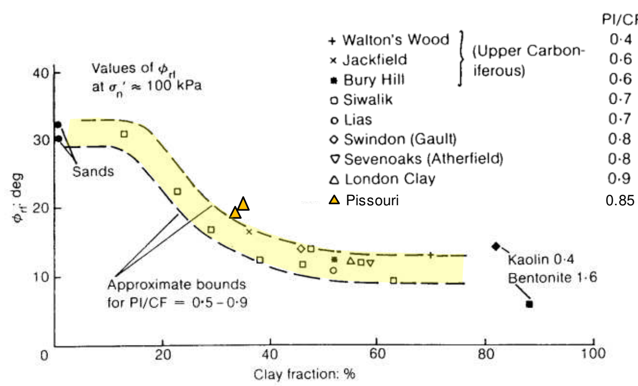

Figure 8. A comparison of the residual angle of shearing resistance of the weathered Pissouri marl with the dataset presented by Skempton (1985).

GROUNDWATER REGIME

A field survey of the broader landslide area, led to the location of a number of natural springs and a few manmade wells, as well the mapping of distinct stratigraphic and tectonic features. The hydrogeologic regime was further studied by projecting the geological units presented in Figure 3 on a digital elevation model of the broader Pissouri area. Figure 9 presents the outcome of this exercise. The vertical scale of the ground relief is stretched (H/V 2:1) to better depict the interplay of surface drainage patterns and geological structure. From the figure it becomes evident that the more permeable capping sandstones of the Pissouri hilltop comprise the main aquifer of the area. A few wells sunk in the top hill area have been exploited constantly in the past by the villagers and provided the main source of water for the settlement. A study of the drainage pattern indicate that surface water flows in low gradients towards the southeastern edge of the village (Figure 10) and infiltrates the capping sandstone stratum, during the wet season, recharging the aquifer. Subsequently, groundwater seeps towards the slopes surrounding the hill and overflows at specific locations of the contact between the more permeable sandstones with the impermeable underlying marls, as shown schematically in Figure 10. A few seasonally discharging springs and water collecting wells have been located at the southeastern edge of the hill, near the landslide site (see Figure 11), which are exploited by local farmers for irrigation. A probable fault trending NNE-SSW, mapped by Stow et al. (1995), is running parallel to the eastern boundary of the village and dissects the sandstone layer. This fault is believed to control the steeper slopes of the Eastern side of the hill and is probably associated with the presence of the water springs down slope.

The relatively low precipitation in Cyprus and the limited extent of the aquifer, is responsible for its limited capacity and seasonal variability. However, the construction in recent years of a modern water supply and distribution system was apparently followed by the reduction of aquifer exploitation as well as by additional and constant recharging of the aquifer by water leaking from the water supply pipelines, the sewers and the sumps constructed within the built up area. Domestic detergents were traced in the groundwater on samples collected near the landslide site, indicating infiltration of domestic wastewater to the aquifer. It is believed that the additional aquifer recharging by the water supply mains and sewage leakages has contributed to an increased groundwater feeding of the landslide slope. An initially high water table in combination with an exceptionally wet month may have been responsible for exceptionally high pore water pressures within the slope with a detrimental effect on slide mobilization.

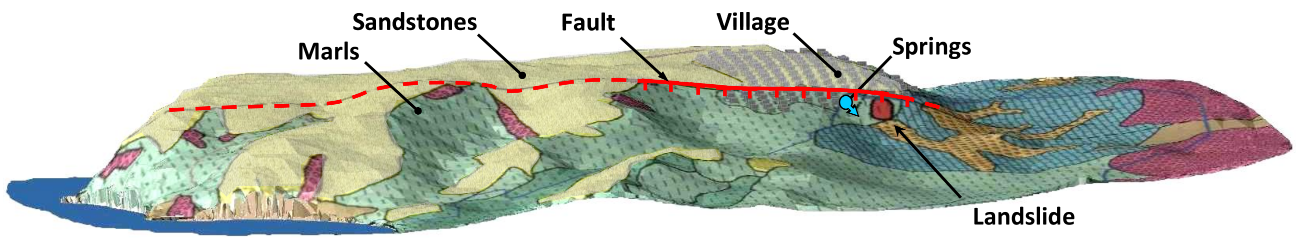

Figure 9. Hydrogeologic setting of the Pissouri area. Geological units (after Stow et al., 1995) are projected on the distorted relief of the Pisourri hill (exaggerated vetical scale H/V 2:1). Location of the landslide and the springs with respect to the major hydrogeologic units are also noted.

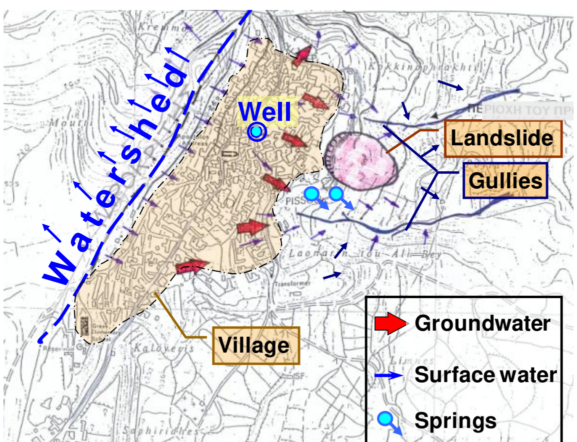

Figure 10. Surface and subsurface drainage patterns. Arrows indicate surface and subsurface water flow. Springs and wells are also noted.

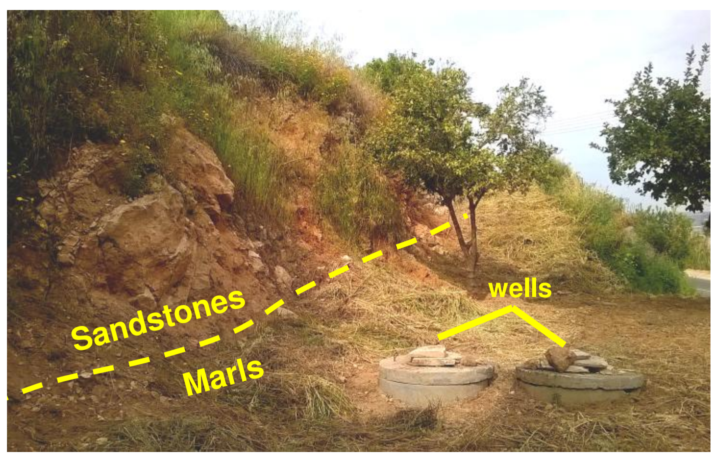

Figure 11. Wells collecting groundwater springing out freely in the sandstone-marl contact area were located a few hundred meters south of the landslide area.

Groundwater flow and pore pressure distribution within the sliding mass was further studied, by analysing simple two dimensional numerical models, which were set up by the finite difference code FLAC. Inflow-outflow equilibrium considerations, in conjunction with the seepage analysis, performed by FLAC, provided an additional means to study and verify the water infiltration, movement and outflow pattern in the landslide area. A typical seepage model representing the eastern slope of the village, is illustrated in Figure 12. The piezometric lines have been computed on a number of transverse and longitudinal sections and were used to build the three-dimensional model presented in Figure 13. The inferred piezometric surface is found at shallow depths, in areas where vegetation growth is more intense, as observed in aerial photographs, (Figure 12) and compares well with groundwater level measurements from piezometers installed in the vicinity of the landslide. The piezometric surface of Figure 13 represent the average dry season water table. During a wet season the water table within the landslide mass is expected to rise significantly and the development of a perched water table during thunderstorms should also be considered.

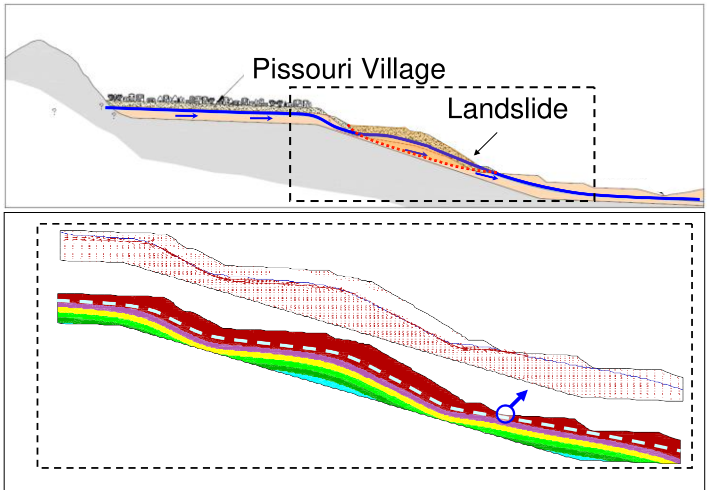

Figure 12. Typical results of the seepage analysis (flow vectors and pore water pressures).

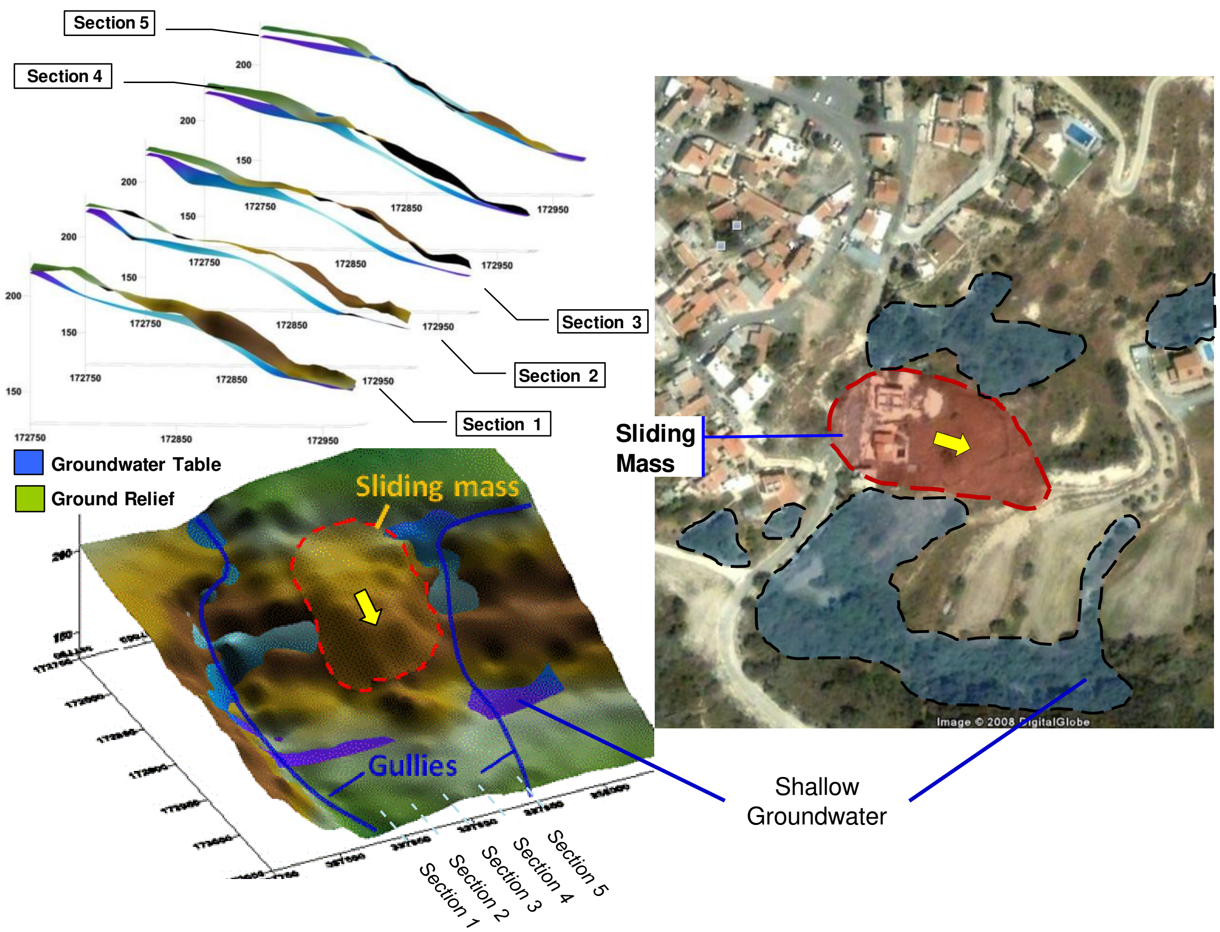

Figure 13. Left: A digital elevation model of the landlide area, overlain to the surface of the computed groundwater table. The groundwater table geometry is also presented as a series of sections in the upper figure.
Right: Blue areas in satelite image indicate areas where the ground water table is at shallow depth and coincide with the most densely vegetated areas.

BACK ANALYSIS

A series of back analyses was carried out, to investigate the general stability conditions of the slide with respect to both groundwater conditions and shear strength values. Back analyses were also used as a means to calibrate the numerical models employed, for the subsequent evaluation of the performance of various landslide remediation strategies. The models were set up by the commercial finite difference code FLAC, and the available factor of safety was determined in each case by the strength reduction method. The failure surface was modelled via interface elements, incorporated in the code and the mobilized shear strength values were determined by gradually reducing c' and tan(φ') values, until the slope becomes unstable. A number of values of the interface initial angle of friction φ' were tested, to determine the respective cohesion necessary to mobilize the slide. In this way a wider spectrum of sliding compatible parameters is covered. This exercise was performed considering both the dry season low water table and an elevated water table representing the wet season. The dry season water table was inferred by the available piezometric measurements and the seepage analyses of the slope previously presented, while the elevated water table was drawn on the basis of steady state seepage analyses performed considering an elevated upstream recharging boundary and some intuitive adjustments to account for rainwater infiltration, which was not modelled explicitly. A synopsis of the mobilized shear strength parameters on the slip surface are presented in Figure 14 where the inset figures depict the considered low and high water table for the two cases examined.

These analyses manifested the fact that an elevated water table can mobilize the weathered marl crust with operational shear strength parameters close to the peak values, as they were determined by the shear box tests performed on the soil samples. They also show that the slide remained mobile after water table lowering, (dry season) if the operational strength values of the weathered marl crust at the failure surface were close to the residual strength values, determined by the ring shear tests. It is concluded that most likely we deal with a new slide, which was brought in the verge of failure due to gradual loading of the upslope area with scree and manmade fill and the gradual progression of the weathering process. The development of high water pressures triggered an already mature slide, which continued to be active even during the dry seasons due to the drop of the shear strength values from peak to residual.

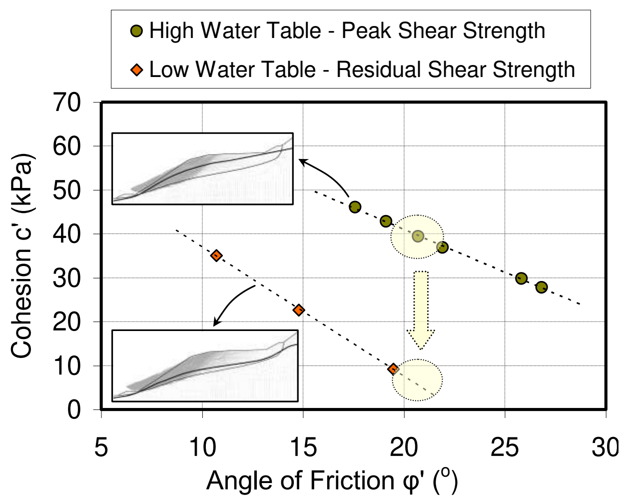

Figure 14. Back analyses results. Estimated mobilized shear strength parameters for a higher and lower water table coincide with the transition of shear strength values from peak to residual.

LANDSLIDE REMEDIATION

The most important requirement of the landslide remediation works was the restoration of the country road that was crossing the upper part of the slide. However, in order to reconstruct the road a significant amount of fill was necessary to be placed above the neutral point of the slide, an intervention which has a detrimental effect on the overall stability of the sliding mass. The protection of the buildings further upslope above the back scarp of the slide, from retrogressive propagation of the slide, was also a major concern. Requirements for construction speed, controllable cost and local availability of materials and equipment imposed further constrains to be considered during design.

In order to develop a robust remediation strategy and to meet the value engineering requirements set by the district administration, alternative stabilization strategies were considered, coherent design options were developed, and subsequently evaluated in terms of economy, constructability and environmental compatibility. A wide spectrum of alternatives was investigated. An initial thought to completely abandon the site and deviate the road did not prove to be feasible. Stabilization of the slide solely by a high and massive toe stabilizing buttress proved also impracticable. Consequently the construction of a modest toe buttress and the simultaneous reduction of ground weight at the upper part of the sliding mass via ground removal and its replacement by lightweight material (EPS geofoam) was the first option developed. A second option involved the construction of a medium sized toe buttress, the trimming of the upper part of the sliding mass to remove as much of its weight as possible and the dowelling of the remaining soil mass, by means of large diameter bored concrete piles. Outline design of the two alternatives are presented in figure 15.

The last option proved to be more robust, reliable, cost effective, and better fit to the constructability requirements, since it required materials, equipment and expertise available locally on the island. It was also found that it had a smaller impact to the landscape and the environment in general. After deciding to adopt this solution, the design was further developed, the construction procedure was studied more thoroughly and every construction stage was checked by means of detailed stability calculations. The layout of the adopted solution is presented in figure 16. The lower part of the landslide is stabilized first by means of a toe buttress fill resting on a drainage blanket, to allow for unobstructed drainage of the natural ground behind it. For the existing gullies running along the two sides of the sliding mass, erosion protection works (lining of the stream courses with gabions) were foreseen to protect the native soils and the toe buttress. Bored piles 1.20 m in diameter were placed in a staggered, 12×12 m pattern further up on the trimmed slope, to dowel the existing slide surface, but also to prevent shallower slides on pre-sheared surfaces from being mobilized, especially during the anticipated development of perched water tables during the more intense rainfall events anticipated. Along the downslope borderline of the road, a row of bored piles, 1.20 m in diameter at 3.0 m spacing, was designed, to reduce the amount of fill necessary for resetting the road pavement at its initial elevation and to ensure the integrity of the road pavement from ground movements. Sewage pipes running under the road pavement were carefully constructed to ensure that no leakage would escape and infiltrate within the sliding mass. The back scarp area which was left by the landslide movement as a degrading steep slope was protected and stabilized by means of a permanent anchored wall. This intervention fulfilled also the requirement to protect the buildings situated on the upslope crest. Groundwater within the remaining sliding mass was decided to be controlled by constructing a trench drain at the back scarp area of the landslide, which would collect the water seeping from the uphill area and discharge it towards the neighbouring gullies.

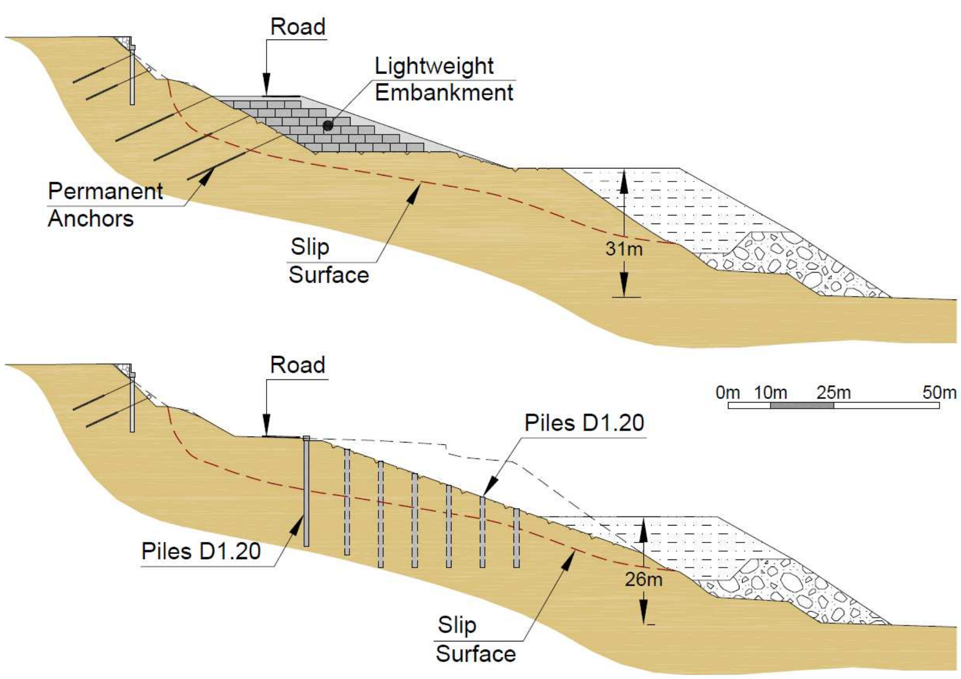

Figure 15. Landslide remediation - Alternative design solutions.

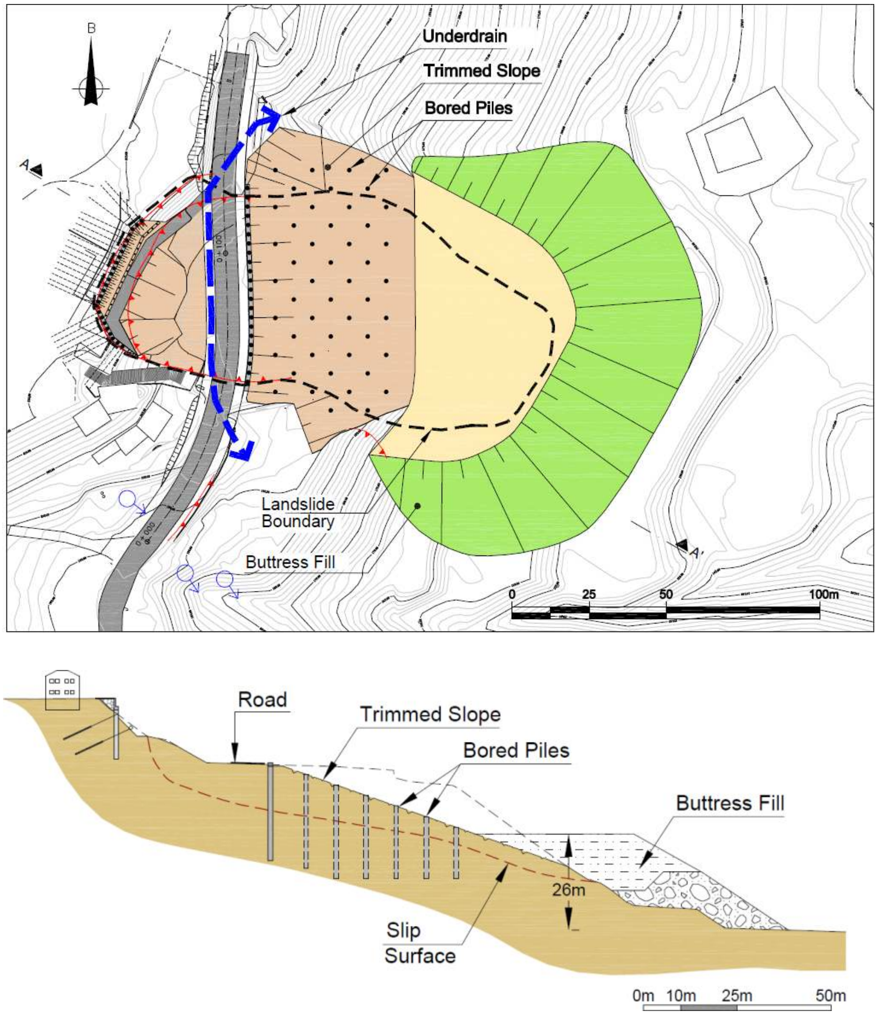

Figure 16. Landslide remediation – Upper Figure: Plan view of the toe buttress fill and the trimmed slope area. Dashed lines indicate general direction of subdrains. Lower figure: a cross section along the landslide.

For the stability assessment of the remediated slope three cases were considered. The first case, representing the sustained loading condition, considered a lowered piezometric line, given the fact that systematic measures are taken to collect the groundwater seeping through the landslide mass. A second case, with an elevated piezometric line, represents a less frequent, high intensity rainfall event, or a malfunction of the drainage system. The stability under seismic actions was also checked through pseudo-static analyses forming the third loading case. The stability analyses were performed by means of finite difference models similar to the ones employed for the back analyses. The models were used to evaluate both the combined effect of all the stabilization measures, but also the performance of individual interventions and their contribution to the landslide stabilization.

The construction of the toe buttress and the trimming of the upslope area of the landslide, lead to sufficient factors of safety (FOS=1.6) under normal conditions (low water table, static conditions), which though drop to low values with an elevated water table and very low values under seismic conditions. It was also observed that these low factors of safety are associated with mobilization of the entire sliding mass. The dowelling effect of the bored piles isolates and stabilizes the upper part of the sliding mass, while the lower part may remain more critical but still with sufficient FoS. Figure 17 depicts the critical sliding mode with and without the dowelling piles. In this case the raised water table yield a FOS = 1.6 and the seismic analysis a FOS=1.15.

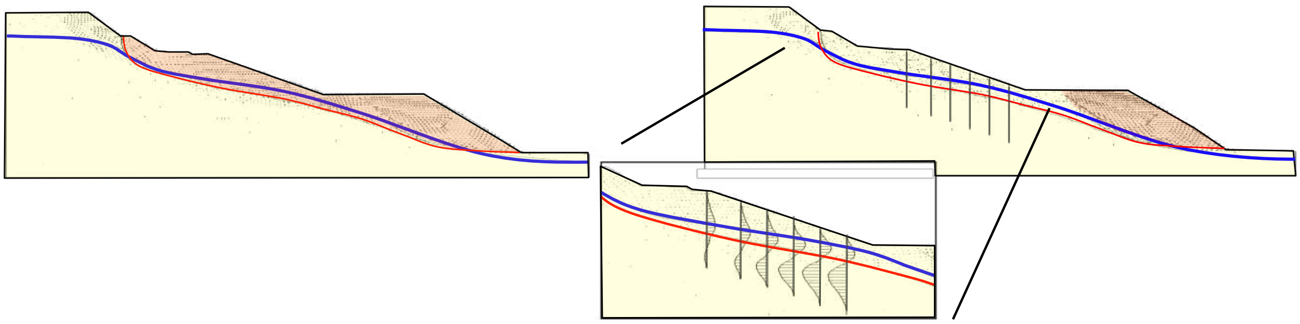

Figure 17. Stability analysis of the remediated slope. Left: Without the stabilization piles the entire sliding mass mobilizes as a single body. Right: With the addition of the piles the toe buttress is more critical.

The construction activities started by constructing the toe buttress (Figure 18) and this stage was followed by the trimming of the upper part of the sliding mass and the subsequent construction of the bored piles (Figure 19). During the execution of the earthworks at the back scarp area, groundwater seepage continuously recharging the sliding mass was indeed encountered as shown in the photograph of Figure 20. Continuous gravel subdrains protected by geotextile shown in Figure 21, were constructed upslope all along the discharging zones, in order to collect and dispose the groundwater before it enters the landslide area. The next construction stage involved the building of a temporary fill ramp, necessary to reach high up to the back scarp area and construct the piles for the anchored wall (Figure 22). The last stage was the removal of the temporary fill, the anchoring and surfacing of the wall and the paving of the road. Figure 23 presents the landscaping before and after the interventions which shows that the works although substantial, had a limited visual impact in the landscape. Monitoring of the structures during the first two years after construction, showed that ground movements were completely ceased.

Figure 18. Construction of the Buttress fill

Figure 19. Installation of bored piles at the trimmed slope surface.

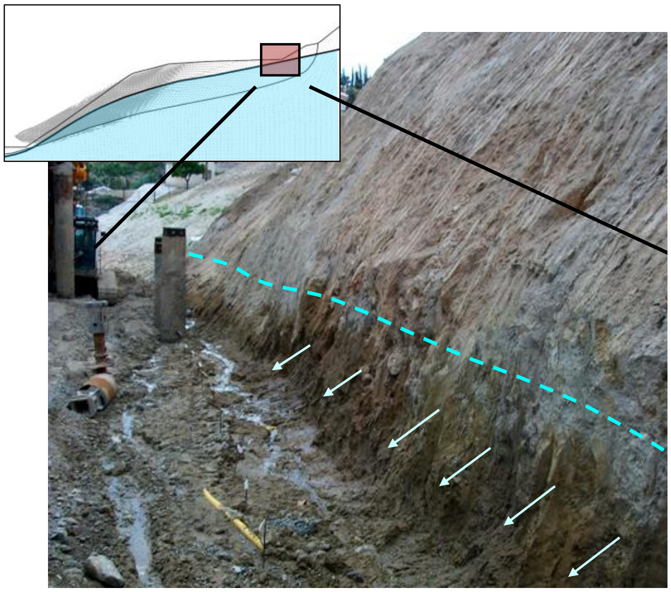

Figure 20. Water seeping out of the marl at the landslide back scarp

Figure 21. Trench drains filled with cobles wrapped in geotextile filter collect and dispose the groundwater.

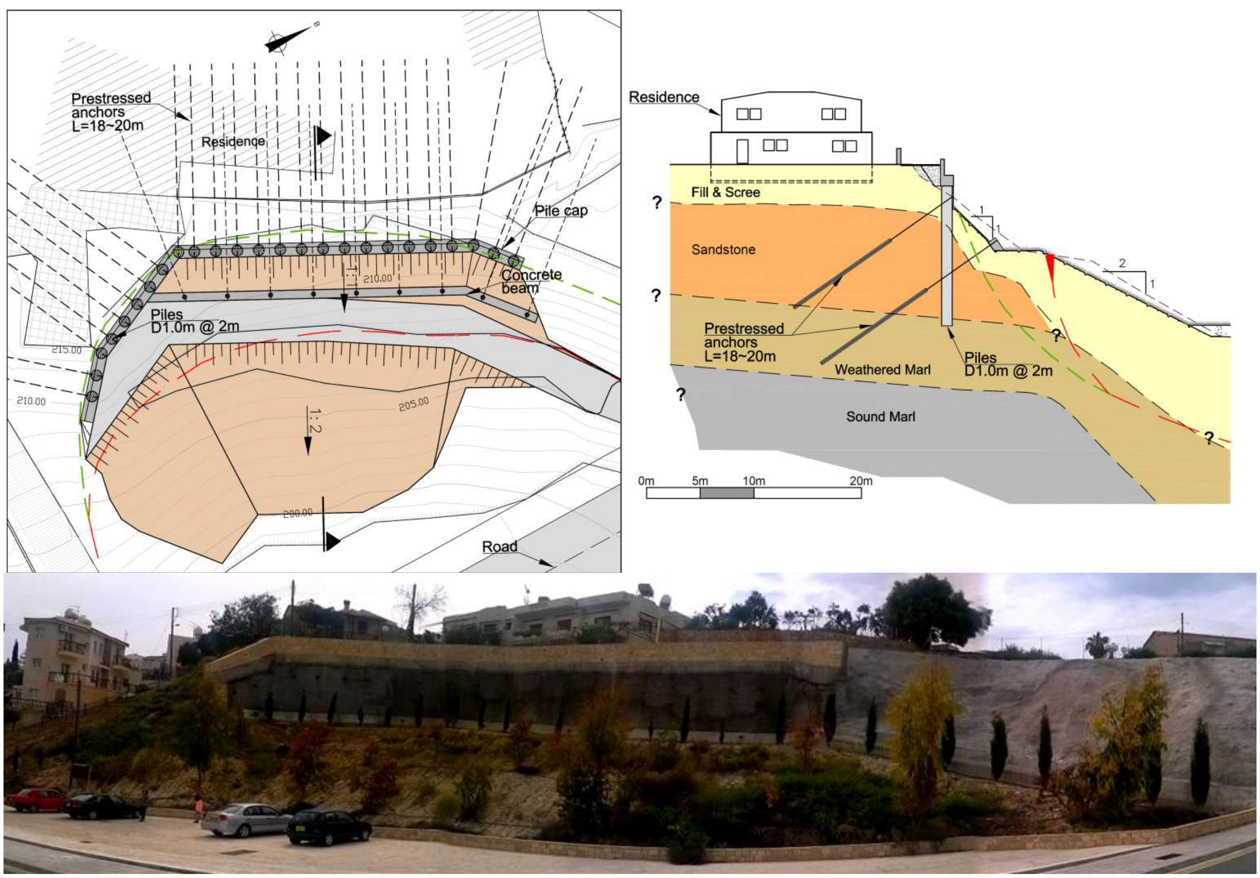

Figure 22. The landslide back scarp area after its stabilization by installing a permanent anchored wall.

Figure 23. The landslide area before (top) and after (bottom) the stabilization works.

CONCLUSIONS

Landslides in Cyprus involve geological formations of weak calcareous or argillaceous rocks and soils, of complex and sometimes chaotic structure. Weathering of weak argillaceous rocks, quickly results in the formation of stiff clayey soil or soil-rock assemblies, which have a strong tendency to slide. Groundwater flow is an equally important parameter. Because of the semi-arid climate of the island and the low precipitation that characterises the coastal areas, most of the villages are situated in localities where geology promotes the development of exploitable aquifers and where manmade wells and natural springs can provide water supply. Thus, it is not surprising that most of the landslides are affecting existing and developing human settlements. Expansion of the villages and the construction of the required civil infrastructure are responsible for changes on existing slope geometry and hydrogeology which are performed without awareness that natural slopes may be in marginal equilibrium. The Pissouri landslide is a typical example of a slide in a weathered marl formation, promoted by the filling of the upper part of the slope and by excessive water seepage.

Understanding the landslide mechanisms in complex geological environments requires an in depth assessment of regional geology, tectonics, and hydrogeology. Undoubtedly some idealization and simplifying assumptions are necessary for geotechnical interpretation. In this paper, it is demonstrated that the development of simple numerical models, at a cost affordable to standard practice, provide valuable means to assess if these assumptions are reasonable or not. Successful back analysis increases our confidence concerning our understanding of the main mechanisms that drive the landslide phenomena we deal with each time. Selection of remediation strategies should cover a very wide spectrum of options. Preliminary design should be developed considering at least two alternatives for a comparative assessment of cost and performance. Significant model and loading uncertainties should be tackled by robust design solutions and this feature provides an essential selection criterion, constructability been the second important one.

ACKNOWLEDGEMENTS

The design of the landslide remediation, as well as the construction supervision, has been carried out by OTM S.A (Athens), in collaboration with P.Papadopoulos & Associates (Limassol), under a contract with the District Administration of Limassol. The geotechnical site investigation of the landslide has been carried out partly by the Geological Survey of Cyprus and partly by the aforementioned J/V. The construction has been undertaken by the CJV Cybarco SA-Iakovou bross.

The authors wish to acknowledge the District Administration of Limassol, engineering and technical staff, for continued collaboration during the design and construction stage. P.Vettas and M.Pachakis from OTM S.A. as well as P.Papadopoulos, provided guidance, and insightful comments during the course of the project.

REFERENCES

Charalambous M. and Petrides G. (1997). "Contribution of Engineering Geology in the planning and development of landslide prone rural areas in Cyprus." *Proc. Engineering Geology and the Environment,* Balkema, London, UK, 1205-1210.

Hadjigeorgiou J., Kyriakou E. and Papanastasiou, P. (2006). "A Road Embankment Failure Near Pentalia, In SW Cyprus." *Proc. Intl. Conference on the Stability of Rock Slopes in Open Pit Mining and Civil Engineering*, The South African Institute of Mining and Metallurgy, Cape Town, 343-352

Hart A. B. and Hearn G. S. (2013). "Landslide assessment for land use planning and infrastructure management in the Paphos District of Cyprus." *Bulletin of Engineering Geology and the Environment*, DOI 10.1007/510064-013-0463-X.

Hart A. B., Ruse M. E., Hobbs P. R. N., Efthymiou M. and Hadjicharalambous K. (2010). "Assessment of Landslide Susceptibility in Paphos District, Cyprus." *Proc. GRSG-AGM Geoenviromental Remote Sensing Conf*, The Geological Society of London, London, UK.

Kyriakou E. and Hadjigeorgiou J. (2008). "Ignoring engineering geology a costly mistake at Pentalia, Cyprus." *Proc. 4th Canadian Conference on Geohazards*, Québec, Qc, Canada, 303-311.

Northmore K. J., Hobbs P. R. N., Charalambous M. and Petrides G. (1988). "Complex landslides in the Kannaviou Melange and Mamonia formation of South-West Cyprus." In: Bonnard C (Ed) Landslides: Glissements de Terrain, *Proc. 5th International Symposium on Landslides*, A.A Balkema Publishers, Brookfield, WI, 263-268

Pantazis T. M. (1969). "The landslides in Cyprus." *Bul.of the Geol. Survey Dept*, 4, 1-20.

Skempton A. W. (1985). "Residual strength of clays in landslides, folded strata and the laboratory." *Geotechnique*, 35(1), 3-18.

Stow D., Braakenburg N. and Xenophontos C. (1995). "The Pissouri Basin fan-delta complex, southwestern Cyprus." *Sedimentary Geology*, 98, 245-262