CULTURAL ROUTES AND REHABILITATION OF THE DRYSTONE RAINWATER CISTERNS OF EPANO MIRABELLO REGION, CRETE.

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ABSTRACT

The cultural landscape of the area at 'Epano Mirabello in central Crete, is well marked owing to two networks: one made by dense small size settlements and another by all kind of drystone constructions. Groups of drystone cisterns are located in special areas, in the intersection of geological faults, in order to collect the surface rainwater. The creation of a cultural route, connecting the most interesting of these locations will offer a double benefit: 1. the restoration and use of the cisterns, 2. an alternative touristical activity capable of creating new work positions.The mechanism of failure, which is associated with the geometry of the cistern, the stones mechanical properties and the quality of the soil around (estimated by a geophysical survey), were investigated for structural integrity and rehabilitation study of these characteristics dry-stone cisterns. The physicochemical chatacterization both of the surrounding soils and the construction materials of the various cisterns was considered as an important tool towards the classification of the conservation state and the consequent decision making of the appropriate interventions. Our interventions aim to restore the cisterns as close as possible to the original, while respecting the existing materials, the original way of building and operating costs, and avoiding materials and techniques that will alter the monumental nature of such cisterns.

INTRODUCTION

The 'Epano Mirabello' region is located in central Crete (Municipality of Aghios Nikolaos), between the touristic areas of Malia and Elounda, with the national road to the south and the Cretan Sea to the north. The character of its land is based on the calcareous plattenplak and narrow basins where the inhabitants have intervened with drystone constructions such as windmills, retaining walls, division walls and cisterns.

The area is wholly composed of squamous blocks of stone, the platey limestones of the Tripolis Zone, while its lowland shows a continuity of Phyllite and Quartzite. The slabs dominate the landscape formation, which is perceived uniformly in all the adjoining areas, with constant flora; of a kind that penetrates more easily through the limestone cracks and conveys the impression of a mountainous, infertile land.

In this near forgotten corner of the Cretan landscape, emerged a kind of agricultural economy based on livestock farming and the cultivation of almond trees. The low retention of moisture by the limestone and the presence of water at very low level subterranean passages, led to a string of inventive ways for securing water during the summer months. There were wells at the lower strata (layers), and closed cisterns at the higher, and yet the place's peculiarity lies in the drystone cisterns dug into the earth like open wells with a large diameter. The choice of the location of the cisterns is always linked to the natural drainage pools; they are usually laid out in groups and are almost always constructed with the prospect of shared communal use.

Briefly, the cultural landscape of the area is well marked owing to two networks: one made by dense small sized settlements and another by all kind of drystone constructions.

The aim of the research is to investigate the genesis of the open cisterns, the logic of their spatial arrangement, their relationship to the settlements and the character of their structural behavior. As a secondary approach, the identification of the whole of these peculiar underground structures as an important testament to the age-old search for ways to secure water, and their importance in structuring the peculiar surrounding landscape, would lead us to investigate the possibilities of reclaiming the cisterns considering two components: *A).* Their rehabilitation as cisterns, thus maintaining their original use and *B)* Their prominence as a structural element belonging to a larger monumental whole, characterized as a water network.

In order to reach our final goal, which is the planning of a cultural visitors' network linking together the cisterns as well as proposals for their structural rehabilitation, the following research has been under way: 1. Mapping of the area's geological drainage basins, 2. Mapping of the plattenplak limestone, led by the professor of Geology Manolis Manoutsoglou (Technical University of Crete), 3. Geophysical prospecting at three selected points/ groups of cisterns, led by the professor of Geology Antonis Vafeidis (Technical University of Crete), 4. Physico-chemical analysis of construction materials of the cisterns and the surrounding soil at selected areas, 5. Study of structural integrity, 6. Proposals for structural rehabilitation and 7. Design proposals for the cultural route.

PHYSICOCHEMICAL STUDY

The Physico-chemical characterization of the construction materials and the surrounding soils provided invaluable information for the objectives of this research and demonstrated the potentials of the implemented interdisciplinary approach. In particular, the Physico-chemical characterization concerning both the surrounding soils and the construction materials of the various cisterns can be considered an important tool towards: (a) the classification of the state of conservation, (b) the way the chemical composition and the soil grain size could influence the water retention and (c) the consequent decision making for applying appropriate interventions, with compatible conservation techniques and materials.

The analyses indicated that soils rich in allumino-silicate minerals retain water better than soils containing a considerable amount of carbonate minerals. The X-ray diffraction analysis reveal that the soils from Kourounes contain illite, kaolinite, quartz, myscovite, hematite and feldspars, while the Vrouxas and Dilakkos soils are adittionally charecterized by the presence of calcite. Figure 1 illustrates the major element concentration in the soils identified by the Energy dispersive X-ray fluorescence (EDXRF), where the differentiation in the Ca, Si and Al concentration among the Kourounes and the other soils is evident. The results of the elemental composition of the soils were also confirmed by the differential themal and gravimetric analysis (GTA-TG). This analysis confirms the presence of calcite in the Vrouxas and Dilakkos soils, as well as the high argilaceous content in the Kourounes samples along with the higher amount of absorbed water that the other two soils. In addition the Vrouxas and Dilakkos soils contain organic matter which assistes in the aggregation of the soil grains, thus facilitating the microstructure of the ground in the filtration of the water.

Differences in the mineralogical and chemical composition were also associated with differences in the soil grain size distribution, as is illustrated in Fig. 2. The soils K1-K3 with a high clay content contain fine aggregates with diameters lower than 1 mm, while the other two soils exhibit grains with size lower than 5 mm. These grain size distributions classify the Kourounes soils as uniformly distributed sands, while the other two soils can be considered as well distibuted. The well distributed soils contain both fine and coarse grains which play an important reole into the water filtration. The uniformly distributed grains with a high clay content contribute to the retention of water and, therefore, a very common phenomenon is the water stagnation.

From the above results becomes evident the role of the features of soils in controlling the water filtration and allowing the whole system to resist and accommodate better to external shear and compressive stresses. The analysis of the construction materials of the cisterns evidenced that platy limestones of low porosity and water absorption have been employed. The platy limestones show a water absorption by saturation equal to 0.22% and a water capillary coefficient equal to 3E-05 g cm^{-2} $s^{-1/2}$. The employment of platy limestones as construction materials for the cisterns can be justified by the low values of water absorption.

By combining the results of the physico-chemical analysis of the surrounding soils and the construction materials of the cisterns it can be concluded that the system soil-stone determines the water retention. Therefore, any intervention should be characterized by compatible materials to the original. Within this framework restoration mortars with binders of hydrated lime and pozzolan and aggregates of quartz sand with grain size up to 2mm are proposed. Previous works indicated that these mortars provide a mechanical strength ranging from 5 up to 8 MPa [1].

STRUCTURAL INTEGRITY

Research about structural integrity and rehabilitation study of these dry-stone cisterns were done to typical forms of the examined cisterns. Laboratory tests were done for the determination of compressive strength and indirect tensile strength and the modulus of the rock masonry and *g*eophysical surveys were done for the territorial formations *g*eophysical surveys were done for the territorial formations from Laboratory of Rock Mechanics, Department of Mineral Resources Engineering (Z. Agioutantis) and the Department of Mineral Resources Engineering (E. Manutsoglu) at Technical University of Crete, respectively. From analysis with and without the presence of water identified areas that need strengthening and building restoration.

Specifically in Vrouchas no major structural problems except in specified areas where either we have the collapse of the masonry (presumably due to human intervention) or severe deformation will lead to future failure (Fig. 3a). Reinforcement is the circular shape of the cisterns and the uniformity of the soil around them. Unlike in Kourounes several parts of the cisterns are damaged. This mainly comes from human intervention and the characteristics of the surrounding soil (coarse sand and clay are impermeable to water, soils with good shear strength and low compressibility). Resulting in the collection of large quantities of water in the surrounding area and the almost complete coverage of the cistern and surrounding area for a long time. In Dilakko we have three cases: Circular tanks with walls of small inclinations to the vertical which are in fairly good condition. A small circular cistern with walls of small negative slope, which raises the question whether it was initial a closed cistern and a large cistern with walls of greater inclination to the vertical, which has largely collapsed. Our investigation is focused to the mechanism of failure which is associated with the geometry of the cistern and the quality of the soil around it, which varies from well-graded sands in areas with squamous limestone. According to surveys it may not have initially circular shape of the wall, but it followed the format established depending on the terrain. According to the results of geophysical survey, the first 12m observe figures given in limestone, then a layer characterized by karst limestone rock with mixtures of clay materials and end regions suggest the existence cavities filled with clay materials or water, and thus a possible communication between adjacent cisterns. These results combined with field observation and the failure mode (collapse of walls in the area showing aluminous soils and an integral wall near the rock formation), suggesting that surround the large cistern based on different qualities of soil in which If there are specific charges (e.g. earthquake loading or human factors) led to failure in the masonry, (Fig. 3b). Also earlier interventions in the crest of the walls proved inadequate.

Based on the topographic mapping and the experimental measurements of structural materials and soil classification standard forms of cisterns were analyzed with computational methods in their resistance and static adequacy [2, 3]. The finite element method was used for the structural simulation. Specifically two dimensional plane analysis were done, using isoparametric, quadrilateral finite elements for the simulation. Regarding the behavior of masonry and the connection between masonry materials two assumptions were considered: a) full connection between the masonry materials (*Continue model*) and b) partial connection between the masonry materials (*Contact model*) [4]. For the outer layer of stones and the smaller stones to fill the back surface, two simulations were used: a) *Detailed simulation* masonry using different mesh for stone, mortar, and soil and b) *Simplified simulation* for masonry using rectangular finite elements. Finally two types of ground were assumed: *soil* and *rock*.

The following finite element models were studied:

Model A: Detailed simulation was used and the walls of the large cistern were simulated with an inclination to the vertical. Total cistern depth equal to 6.5m (Fig. 4a).
Model B: Detailed simulation was used and the walls of the large cistern were simulated with zero inclination to the vertical. Total cistern depth equal to 4.5m (Fig. 4b). Additional two cases were considered, first, *B1*: Continuous model and second, *B2*: Contact model.
Model C: Simplified simulation for masonry using rectangular finite elements was used and contact model was assumed, to *Model A* geometrical model.
Model D: Simplified simulation for masonry using rectangular finite elements was used and contact model was assumed, to *Model B* geometrical model.
Considering vertical gravity loads, the results of analysis for the continuum model showed that for the large cistern (model A), horizontal displacements increase with the height of the wall, starting from the height of 2.5m from the base and showing maximum displacement at the height of 4m, which is the marginal wall height of the continuum model A. In the case of small cistern (model B), the maximum horizontal displacements occurred at the upper edge of the wall (Fig. 5), considering either contact model or continue model. The analysis of simplified models (Fig. 5), showed that the horizontal displacements for great cistern (model C), appeared maximum at the 2.3m from the base, while for small cisterns (Model D), the maximum displacements occurred in 1.3m when there is rock around and 1.75m for soil, respectively.

STRUCTURAL REHABILITATION

From analysis it was shown the smoothing effect of water in the cisterns, which limited the horizontal movement of the masonry. The ability of movements between the stones, which was simulated by model of contact-friction leads to larger movements at the top and upper wall. Also the existence of clay soil formation leads to a larger movement which leads to failure of the wall than in the case of rocky formation.
About the walls of cisterns in Vrouchas, these are in fairly good condition, demonstrating the adjuvant effect of the circular form of the wall which leads to more evenly around the pressures from the ground. These presented only local problems of hardware failure, low corrosion and poor protection of the crown. It recommended a good cleaning, a local reinforcement of the walls showing signs of strong deformation or erosion and finally to overlap with the coronation mortar compatible with existing materials which will enhance the coronation of the wall, it will stabilize stones tend to move and it will also protect the erosion of the wall of rain in the structure of the wall. Additional to the above proposed restoration techniques, for the large cistern in Dilakkos, new wall must be build, using stones from the surrounding area and with original way of building. Strengthening of the connection between the new and the old wall must be done. A mortar with increased strength and possibility of large deformations was suggested, which is also compatible with existing materials.

RESULTS

In the small geographical area of Upper Mirabello, air and water led people to form their rocky land into a place at once familiar and cohesive. The ways of taming the natural forces modeled the area’s cultural landscape, an organic unity of land and structure, where peoples’ actions and customs were forged in the fertile relationship with local materials; guided by a sense of economy in managing resources and a logical grasp of the annual succession of the seasons. The significant local character of the cisterns, combined with other drystone structures congruent with the process of drawing water, provide the architect with the capacity to recreate the way in which these spaces could become connected as a cultural route, in harmony with the countryside’s development.
The abandonment of the poor land has caused the gradual destruction of human artefacts. In the meantime, the great pressure of the massive coastal tourism needs some kind of intechanges with the poor mountainous interior of the island. The creation of a cultural route, connecting the

most interesting of these locations will offer a double benefit: 1. the restoration and use of the cisterns, 2. an alternative touristic activity capable of creating new employment.
In Upper Mirabello, the stone structures, which conserve energy and water, mills and cisterns, constitute the relative majority, in terms of monumentality, in relation to other areas in Crete. We attempt to intervene in this particular group of monumental constructions in order to: 1. Ensure its structural preservation, 2. Consider the possibility of managing the whole as part of the productive process, 3. Promote selected areas as quality touristic attractions and
4. Direct pilot interventions are proposed and other activities towards achieving a denser habitation in the area.
Based on the analysis of the materials of the place and the stone structures as well as on the drainage basins revealed by the geological survey, the following commitments arise:
1.Our interventions aim to restore the cisterns as close as possible to the original, while respecting the existing materials, the original way of building and operating costs, and avoiding materials and techniques that would alter the monumental nature of such cisterns.
2. No alterations are to be made to the upper layers of the soil, which could have irreversible repercussions for the maintenance of the natural local environment's hydraulic balance. Therefore any future work should not incur changes in the soil's composition of the soil; this would mean no transfer of soil from the site as well as no mixing with other types of soil if they do not originate from the same place. Thus we are obliged to maintain the given balance.
3. Utilization of limestone rock from the cisterns' immediate environment; this would entail use of material from older wear which have collapsed on the base of the cisterns.
4. Any new structures ought not to alter the hydrologic balance of the area. Drainage should continue to function in the same ways and with the same rhythm.
5. The work should not only aim towards the traffic of visitors by giving prominence to the monumental drystone structures but should also to contribute to further use of the cisterns as water reservoirs.

CONCLUSIONS

Our general arrangement rehabilitates the existing cisterns according to the structural study and their perimeter is crowned, according to the proposal, with stone and binding mortar. In Kourounes, new drystone structures are provided, serving the delineation of a large new irregular basin. In this way that will allow the increase in water capacity combined with the restored still existing circular cisterns. Stone pavements, using local material are provided as continuation of the old paths. In selected areas between the circular shapes, a new arrangement is proposed using the local Fourni stone slabs in sizes of 30cm x 5depth.
Protective railings placed in a circular arrangement will be located at selected parts of the three groups of cisterns. In Kourounes, a raised steel walkway will be built, in relation to the ground level, 28m in length, in order to permit the visit during the winter time. A shading structure will be placed in contact with the large threshing-floor, in the higher point of Dilakko area (Fig. 6). This will be a steel structure composed of vertical and horizontal metal elements and wooden planks as final upper overlap (Fig. 7).
In the future, other cultural routes could contribute to the growth and denser habitation of the region, such as that of the windmills, monasteries or certain parts of old connecting roads between settlements. The network of settlements is dense and rich in terms of building reserve; thus it is in the position to accommodate future inhabitants in a balanced way of living.

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FIGURES

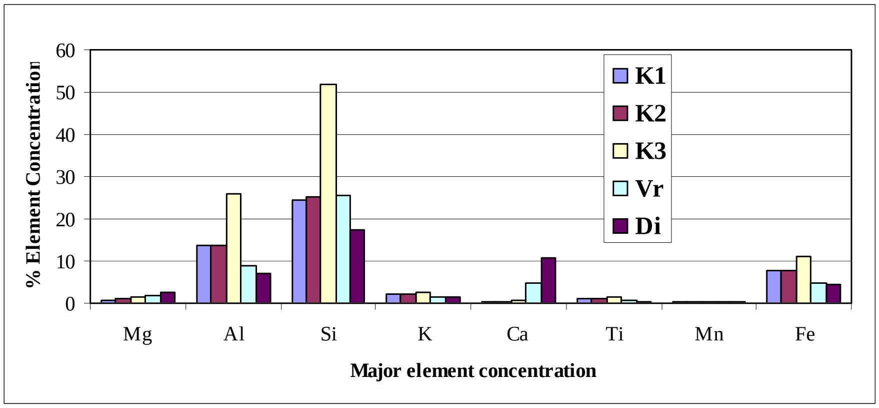

Fig. 1: Major element concentration in the soils from Kourounes (K1-K3), Vrouxas (Vr) and Dilakkos (Di).

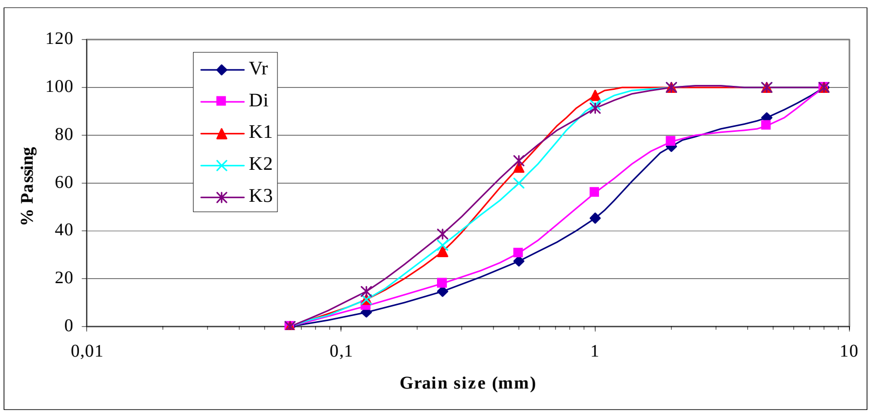

Fig. 2: Grain size distribution of the soils

Figure 3: a) Large cistern in Dilakko, where a large section of the wall is collapsed and b) Circular cistern in Vrouchas, where section of wall and the concrete crown are collapsed.

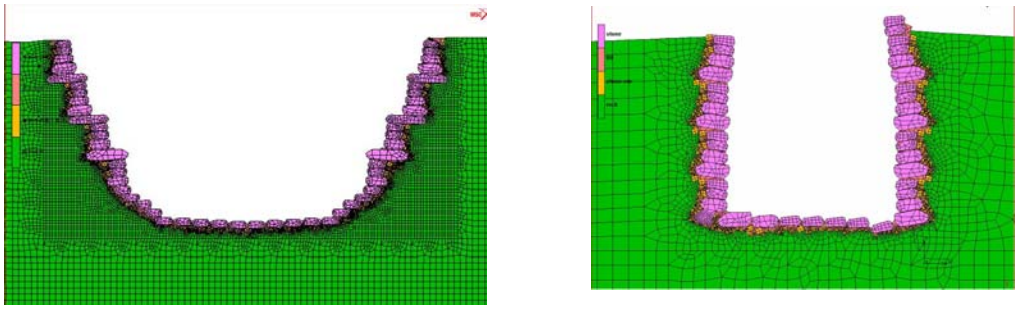

Fig. 4: a) Model A (large cistern, inclination of walls), b) Model B (small cistern, vertical walls).

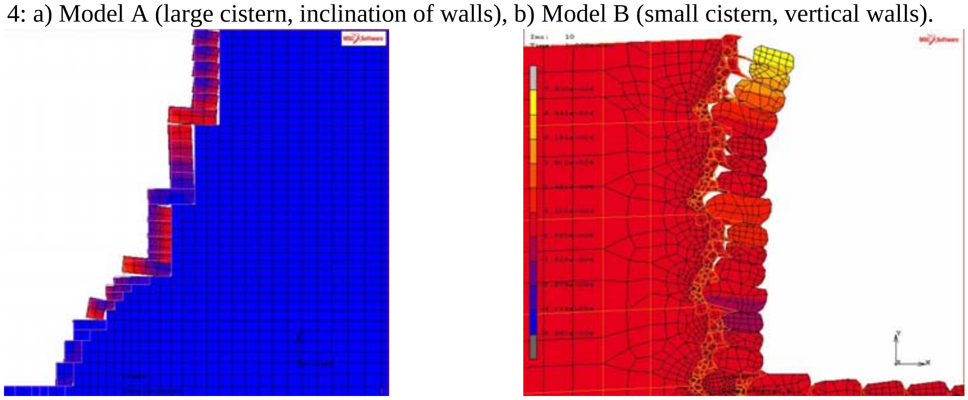

Fig. 5: Deformed shape of a) Model C (large cistern, inclination of walls) and b) Model B (small cistern, vertical walls).

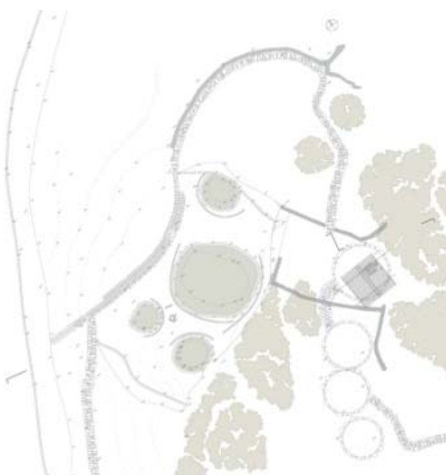

Fig. 6. Dilakko cisterns area with the circular threshing-floors, above.

Fig. 7. Dilakko cisterns area. The protection rails and the new drystone path.