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AKKALE CISTERN IN MERSIN-ERDEMLI: STATIC ANALYSIS AND RISK ASSESSMENT

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ABSTRACT
The paper deals with the structural analysis of the ancient cistern located in archaeological site of Akkale in Erdemli (Mersin) in Turkey. The cistern, even though discovered many years ago, has been for longtime abandoned. Recent policy is oriented in reuse of the structure, as archaeological/monumental site, as well as to rehabilitate the architecture in order to preserve it. A team from University of Rome "Tor Vergata" and from University of Mersin, organized a surveying campaign for structural analysis and evaluations on existing conditions of the building, its material and structural risk assessments, since the site will be opened to visitors. Surveying activity of the geometry of the monument and limited analysis of samples collected on site provided basic and ineludible information to use in the subsequent numerical/geometric analysis. The Cistern is one of the biggest closed reservoirs of ancient Olbian region of Eastern Rough Cilicia from late Antiquity Period, realized partially buried in the soil, with a large roof supported by a double order of masonry arches. The analysis has been carried out performing standard simplified approach, but also comparing the results with more sophisticated Finite Element models. The results of the analysis are encouraging, and it seems that only limited works should be done in order to allow visiting people inside the structure. Further and periodical chemical analysis are suggested, in order to monitor the state of the material and the possible decay.

Keywords: *Akkale, Cistern, Masonry Structure, Structural Analysis, Risk Assessment*

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1. INTRODUCTION AND HISTORICAL FRAMEWORK

Erdemli-Silifke coastal region (Mersin), which was called as the *Olba Territorium* in Eastern Rough Cilicia during ancient times, possess one of the richest water works and rainwater cistern systems of classical times. Need for fresh water is one of the crucial factors in development of cities throughout history. The hot and drought climate of the region caused scarce surface and ground water as similar today. For this reason; important settlements of the Olba region were supported by fresh water collected from springs of higher sections of the Lamas Valley and transmitted via underground galleries, surface water channels and aquaducts travelling approximately 30 km. distance. During the Roman and Late Antiquity periods, there were three remarkable water works in the region: Olba, Diocaesarea, Elauissa Sebaste-Korykos water systems (Bildirici, 2009). These historic water systems are named after the cities that they used to serve. Among them; Eluissa Sebaste-Korykos water system was developed to transport water from the Lamas Valley to the important coastal settlements of Elauissa-Sebaste and Korykos. The fresh spring collected at 100 m of the Lamas Valley and 17 km away from Kızkalesi was transmitted through galeries (1.5 x 1.5 m) carved into the western façade of the valley towards the Kayacı location by coastal plain; and then transferred along the coast passing hills via surface water channels and valleys via aquaducts until the port settlements of Elauissa/Sebaste and Korykos located in the west (Bildirici, 2009). This water system has seven aquaducts in total; which makes it remarkable when compared to other two systems of the region.

Akkale, located in Tırtar of Erdemli town today, was one of the important ancient port towns of Olba Territorium during classical times. Archaelogical surveys conducted by Mersin University Research Centre of Cilician Archaeology (KAAM) and Mersin Museum since 2017 proved that ancient settlement of Akkale used to be small but important settlement functioned as a port facility housing significant monuments such as harbour bath, accommodation facility (inn), public cistern, monumental tomb and remains of religious buildings (Aydınoğlu, 2017). There is one of the largest public cisterns of Olbian region located in the centre of this facility, which is called as Akkale cistern. Archaeological surveys also showed that remains of water channels that led from Elauissa-Sebaste Korykos water work towards Akkale. Moreover, there were other water structures excavated nearby Akkale cistern indicating that there was an integrated water distribution network through the settlement. Akkale cistern could have functioned as the main reservoir of this harbor facility, where the water taken from Elauissa- Sebaste Korykos water work, was stored before its distribution to important buildings of the settlement such as bath building, fountain (located on the paved street of the city), and even ships awaiting in the harbor.

Fig.1- Large cistern structure in Akkale site.

1.1 Description of Akkale Cistern

Akkale cistern testifies with a potential volume of 7000 m^3 (7 million liter) for activities of local population in managing the harbor traffic and other public representative function. The cistern has rectangular plan with 21.53 x 36.40 m. It was constructed with stone masonry technique which was embedded into rock-cut terrain. North wall of the cistern is supported by terrain while south wall is constructed with stone masonry wall of 1.50 to 1.80 m. thickness. The interior height of cistern is 9.80 m with a vaulted superstructure supported by two rows of arcades. Each arcade has seven arches supported by eight pillars. The cistern has flat roof cladded with cut stone pavements, remains of which can be seen today.

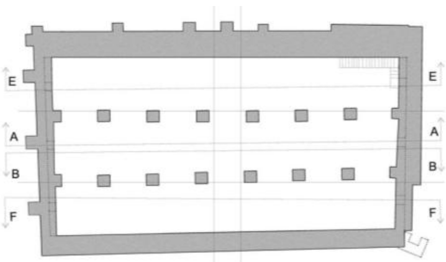


Fig. 2 – Plan of the Cistern

There is secondary masonry wall attached to west facade of the building which was used as walking platform to enter into the cistern. There are three window openings in this facade, where the third one located in the south opens to stone stairs leading into the cistern. It must have been used for control and cleaning of the reservoir as typically seen in ancient public cisterns of the region. The top level of east facade is slightly demolished; but remains of window sills show that there must have been three windows on this facade as well.

Fig.3 – Transversal cross section of Cistern

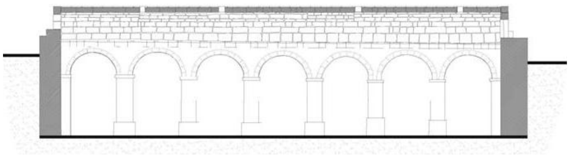


Fig.4 - Longitudinal cross section of Cistern

2. AIM OF THE PAPER

Showing a valuable example of ancient hydraulic engineering of the Olba region; Mersin University, Mersin Museum (Ministry of Culture and Tourism) and Çukurova Regional Development Agency joined their institutional capacities in order to conduct historical survey of Akkale ancient settlement, to start architectural conservation process for the ancient cistern and visitor management program for the whole site. The research program named as "Feasibility Research for Survey, Conservation and Presentation of Akkale (Erdemli) Archaeological Sites" has been conducted by a multidisciplinary team composed from archaeologists, conservation architects, geological engineers, structural engineers and city planner; and supported by Çukurova Regional Development Agency and Mersin University during 2017-2018.

Within the framework of this wider research program; this paper focuses on structural surveys that have been prepared in order to contribute to the study of the Akkale cistern. The focus analysis has several targets:

a) to assess historical safety of the structure (cistern) now-as-the-past, trying to understand the behavior of the original structure, as per original construction. It means consider the cistern full of the water, as it could be at the peak of its activity.
b) to assess static conditions of the existing structure (cistern without water), related mostly to the surrounding conditions offered by the terrain and soil characteristics.
c) to develop proposals in order to guarantee structural safety of the building during architectural conservation studies, possible reinforcing/

strengthening activity in local critical parts

d) to guarantee safety during possible cleaning activity inside the construction as well as during possible local excavation activity outside the construction.

e) finally, but not less important, provide some information and suggestions for possible future re-use of the Cistern for visitor purpose.

3. GENERAL INFORMATION ON THE STRUCTURE AND DATA COLLECTION

The existing information available for the structures has been provided after the archaeological and architectural survey of the building. The provided documents include;

- Surveying maps, plans, cross sections, side views, internal and external, provided by a surveying by Total Station equipment. Generally it considers a number of point to be connected afterword in order to reconstruct the imagine of the structure.
- Maps, plans, cross sections, side views, internal and external, carried out by a meticulous, even been still preliminary, reconstruction work, trying to provided most of the information useful to understand functions, structure, construction technique, architectural details of the cistern.
- Preliminary geological and geotechnical investigation on the soil.
- Material information provided by Conservation Laboratory of Ministry of Culture in İstanbul.

The documentation obtained preliminarily has been very useful to perform a satisfactory first level of structural analysis of the construction, as well as to assess risk conditions for several and different situations such as during further surveying, archaeological excavation, local maintenance or reinforcing works, public access to the structure.

The information obtained for the soil mechanic characteristics and the strength/elastic modulus/weight of the construction material needs to be included in the second phase of the research to clarify following questions:

- How much the lateral walls could be considered as part of the construction instead of part of the soil, in the sense that the possible cladding on the wall should be considered not structural
- The same than the previous question, related to the floor (apparently only natural excavated rock surface).
- Is there is any crack in the floor rock or in the wall, which will also testify some settlement (apparently not existing) of the structure?
- Elastic modulus, specific weight, cohesion, hardness, ultimate resistance stress of the different rocks/material available on the site (1-barrel vault, 2-longitudinal arches, 3-columns, 4-lateral wall, 5-filling material, 6-foundation/surrounding local rock).

The visual geomorphology of the site let us presume that the soil surrounding the cistern has some characteristics of limestone rock, with limited fractures.

Several NDT (Non Destructive Test) help much in collecting information on hidden or buried parts, what could be very useful to have the comprehensive picture of the structure and its behavior. Some of those tests, already provided by the geologist team, are listed below:

a) Electric MASW analysis, in order to obtain a deeper information on the subsoil condition.

b) Georadar (also called GPR - Ground Penetrating Radar, Ground Probing Radar), using different kind of antenna, producing different wave length in order to penetrate more into the soil, or, even, if rolled on the wall, in order to know more about the cross section of the lateral structures (plaster thickness, cladding thickness, hardness of different layered material).

c) Structural Endoscopy, where the amount and the size of the cavities will suggest this kind of investigation.

The tests a) and b) where has been carried out, and some additional information has been collected, even though not so useful for the structural analysis, as it could be expected before the tests. In fact the quite large in homogeneity of the subsoil does not help in recognizing difference in hardness of the rocks.

4. GENERAL COMMENT ON THE STATIC OF THE STRUCTURE.

The first, visual, assessment of the structure gives the impression of a solid and robust structure. The quality of the barrel vault and the connected arches, made by quite well cut stones, with very limited thickness of mortar in the joints, let us be confident that this part of the structure is in quite good conditions.

The other structural elements, it means the lateral walls and columns, are in different conditions. The structure of the columns is not completely visual accessible, since covered by plaster or heavy leakage of water, which produces some calcareous deposit on it. Almost the same comment for the lateral walls, covered by plaster and/or calcareous incrustation.

The vertical loads have been obtained assuming the specific weight of the stone, mortar, rocks, according to the experience of the investigation team and the available literature on the subject.

The horizontal loads have been carried out according to the geometry of the structure (thrust of barrel vault and longitudinal arches), from the water pressure (during the "historical" analysis of the past of the cistern), from the ground pressure and also from earthquake.

What we assume valid and reliable is the process to evaluate the static condition of the structure, by analyzing with simplified and traditional method the structure and comparing those results with some global analysis carried out with structural analysis code by computer.

The single specific weight of the materials have been considered in order to perform numerical analysis, as for barrel vault stone, arch stone, masonry wall, filling, columns.

5. GEOLOGICAL GEOTECHNICAL PROPERTIES OF ROCKS USED IN AKKALE RUINS

Extensive geological and geotechnical studies carried out in the field and laboratory shown that most of the construction material for the cistern was limestone blocks. A full report by Güler and Tağa (2018) is available, from where most of the following information are taken.

In the respect of the monument, no sample has been taken from the construction, but several photos and *de visu* inspection. Then most of the collected results come from the analysis of surrounding local material, assumed belonging to the same kind of rocks.

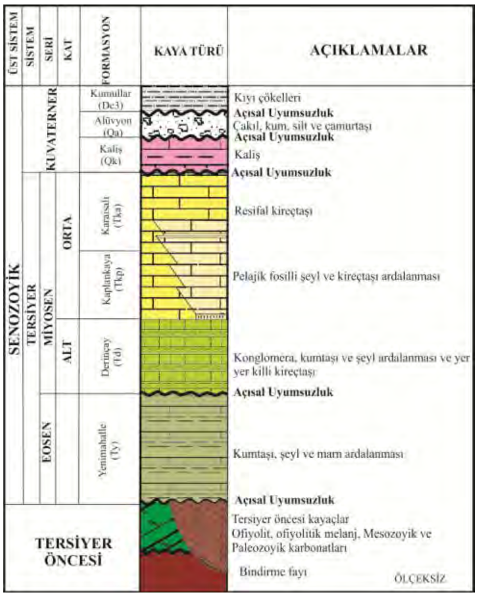


Fig. 5. Simplified stratigraphic section of soil in Akkale (extract from Güler&Taga, 2018)

Mechanical properties of the limestone blocks and bedrock one used in the cistern structure were determined by experiments carried out in the field and in the laboratory. The mechanical properties of rock blocks used in the cistern structure were determined by sonic velocity and Schmitd hammer tests which are non-destructive test techniques (NDT), in respect of the monumental condition of the site. The mechanical properties of the limestone in the bedrock were determined by direct method on the samples taken from the limestone block in the laboratory

In addition, the mechanical properties were determined by bringing the limestone block, which was determined on site, to the laboratory in order to interpret the laboratory experiments with the experiments carried out on the spot (Table 1).

The physical and mechanical properties has been taken from block stones-cylindrical core samples drilled in the rocks, similar at that one existing in the Cistern, in the surrounding. The results are given in Table 2.

Accordingly, average uniaxial compressive strength values of rocks were determined.

The axial deformations occurring at each load stage of the uniaxial compressive strength test of the limestone unit in Akkale site were recorded and the modulus of elasticity was determined. The unit volume weight (γ, kN/m3), uniaxial compressive strength (σc, MPa) and elasticity modulus (E, GPa) of the rock to be used in the restoration of the large cistern in Akkale site were determined in the laboratory (Table 2). Poisson ratio (υ) was determined in the field by ultrasonic test, also non-destructive test techniques.

Table 1. Mechanical parameters of rock blocks in cistern structure determined by nondestructive testing methods (extract from Güler&Taga, 2018)

	Schmidt Hammer		Ultrasonic Speed	
	Ultimate	Elastic	Poisson	Dynamic
	47,51	15,35	0,22	29,59
	51,31	16,57	0,21	19,32
	51,31	16,57	0,21	20,59
	57	18,34	0,21	22,52
	37,97	16,24	0,21	23,68
	78,12	24,42	0,21	31,48
	53,52	17,27	0,21	32,3
	46,2	14,92	0,21	23,76
Max	78,12	24,42	0,22	33,42
Min	37,97	12,14	0,21	12,28
average	54,23	17,22	0,21	21,85
St dev	9,46	2,82	0,00	5,42

Of course such a results, even being correlated according to Son-Reb method, coupling Schmidt hammer and Ultrasonic device, are relatively reliable. But in some way it gives us reasonable values to use as basic information on the construction material.

Tab 2. Mechanical properties of limestone in Akkale site (extract from Güler&Taga, 2018)

Sample name	σc MPa	E GPa
A1	63,27	12,67
A2	39,45	9,00
A3	35,12	9,33
A4	41,15	10,00
B1	42,63	13,33
B2	47,21	12,86
B3	74,62	11,76
B4	69,17	16,55
B6	33,68	16,67
B7	39,48	9,67
n	12	12
Max	74,62	16,67
Min	33,68	9,00
STDEV	13,44	2,52
Average	49,93	12,49

The Elastic modulus of the material is quite high, in fact comparable with that one of a typical concrete for construction. This means that not particular deformation due to concentrated loads could be expected (see the key stone of the arches in the vault, or “tip-toe” of some damaged column) to be measured. It means negligible deformations.

The resistance stress, the limit stress measured of course is a little bit scattered, due to different condition of the tested cores, but the final consideration could be that the value of compressive resistance is quite high, comparable with a soft marble (soft granite), and the medium value appear to be comparable, if not higher, with that one of a good concrete for construction. It means that the material could stand the stress, even concentrated, due to the dead load or other possible (reasonable) live load.

Considering that for the Neapolitan yellow tuff, volcanic soft rock, the value of the porosity range from

20 to 40 % (Aurisicchio et al. 1982), and the value of 15-25 for a compact limestone, the final consideration could be that the construction material of the Akkale Cistern can be assumed to be a good strong and resistant material with a moderate (probably negligible under certain circumstances) porosity. Just for reference, we can recall the compressive resistance value for a good tuff, measured not bigger than 10 MPa, and the value for a compact limestone (soft, hard) ranging from 20 to 100 MPa.

6. SIMPLE ANALYSIS OF THE BARREL VAULTS AND ARCHES

In order to assess the historical stability, in the following has been considered the effect of the water pressure (now not existing anymore) on the external wall. The calculation has been carried out with hydraulic pressure("illo tempore") and horizontal thrust of the arch. As usual, in these simplified schemes, we analyze a slice of the masonry wall, assuming that all the cistern will have a similar behavior of that one analyzed.

Fig. 6 – Inner view of the Cistern

Considering the potential overturning of the lateral wall, due to the soil external pressure and to the water pressure (when the cistern was filled by water) and the opposite resistance given by the weight of the wall and the all the other structure, like vault and filling, the result of the calculation gives:

$$\eta := \frac{M_s}{M_r} = 1.136$$

where η represents the safety from geometrical point of view of the barrel vault and wall under potential water pressure and thrust of arch, by rotation equilibrium at point A (see sketch).

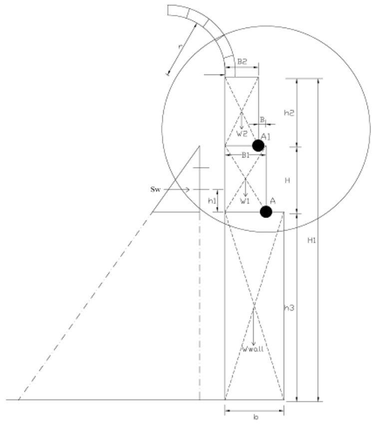


Fig.7- Water pressure diagram and vault thrust on the Cistern wall

Calculation of the stability of the wall has been also performed, with the effect of the horizontal thrust of the arch but without Hydraulic Pressure:

$$V_{arc} := V_1 = 31.008\text{kN}$$

$$F_{Arc\ hor} := \frac{q \cdot L^2}{8 \cdot f} = 15.504\text{m} \cdot \frac{\text{kN}}{\text{m}}$$

$$Th_{arch} = 0.6\text{m}$$ (thickness of the arch)

$$Th_{real} = 0.4\text{m}$$

Rotation around " A" without water pressure

Stabilizing moment: $M_s := 126.588 \cdot \text{kN} \cdot \text{m}$

Overturning moment: $M_o := = 82.171 \cdot \text{kN} \cdot \text{m}$

$$\eta := \frac{M_s}{M_r} = 1.541$$

where η represents the safety coefficient from geometrical point of view for the system barrel_vault-wall in the existing condition with thrust of arch, without water pressure. Rotation assumed at point A (see sketch)

7. THE VERTICAL SUPPORTING STRUCTURES: THE CENTRAL STONE PILLARS

Resistance of the column related to the effect of the vault can calculate by assuming the area above the columns affecting the load on the column itself. The load on the single column can be evaluated:

$$W_{total} := W_{A.influence} \cdot 1.10 + W_{column} = 415.049\text{kN}$$

The compressive stress induced in the material of the columns:

$$\sigma := \frac{W_{total}}{A_1} = 0.288 \cdot \text{MPa}$$

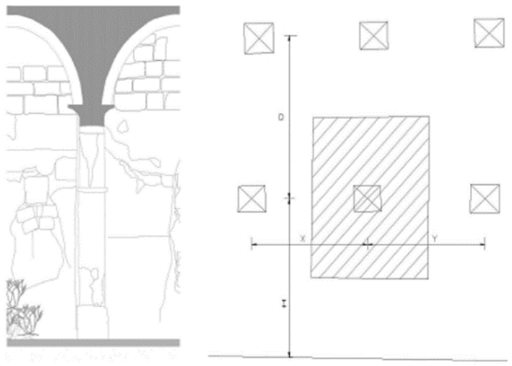
And if Fcd, the reference ultimate stress of the material, can be assumed equal to:

$$F_{cd} := 1.5\text{MPa}$$

then the safety coefficient for compressive stress in the columns can be assessed as:

$$\eta_2 := \frac{F_{cd}}{\sigma} = 5.204$$

We can state that the structural safety coefficient for the columns is quite satisfactory.



Fig,8 – The analysis of a typical central column

8. THE VERTICAL SUPPORTING STRUCTURES: THE LATERAL WALLS

The structural perimetral walls, without further and deeper investigations, are still cryptic.

In fact the structure of the walls of the cistern could be made in different way:

Digged in the local rocky, almost compact material, at the end covered with plaster, to make even the surface. The upper part, emerging on the soil surface, is clearly made by well cut stones, likely local limestone, even brought there for nearby sites;

- Digged in the local rocky, maybe fractured rocky material, at the end covered by an other layer of stones, for structure or isolation purpose. The upper part made by cut stones.

After that the further structural analysis for the static stability of the cistern will be definitely more reliable.

Anyway, as already state at the beginning of this report, the apparent, visible, wall structure, buried as well as emerging, suggests a high level of stability.

9. THE FOUNDATION

As said for the walls, also the foundation suggests several doubts about the geometry and structure morphology.

We cannot assess if the foundation is composed only by the enlarged base of the pillars, even being itself quite sufficient for the dead load (only barrel vault roof and columns resting on each foundation base) or if the base of the columns are embedded in a sort of reverse plate made by material added to the existing soil, to prevent the water leakage, or to add structural behavior.

The visual, limited, inspection suggests the first case, considering the added material as a sort of "water proof" plaster on the pavement.

Despite the fact that a deep investigation has been carried out with georadar and geoelectric investigations have been performed, it is not yet possible give the final answers to these questions.

10. THE GLOBAL ANALYSIS. LINEAR AND NON-LINEAR BEHAVIOR

The structural model prepared in order to simulate the existing structure has been arranged according to the hypothesis described in the previous text. The walls have been considered embedded in the rock, and, where buried, connected to the surrounding soil with suitable mechanical links.

Fig.9-Longitudinal view of the arches in the Cistern

The following figures show the tridimensional FEM models of the considered structure. In the first image we have the drawing of external walls masonry modeled with bi-dimensional finite elements of shell type. In the same image we can see the modeling of the supporting system of the soil, in the detail we have that the structure is partial underground therefore the translations in three directions have been considered as restrained.

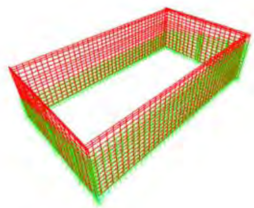


Fig.10-FEM structural model for the only wall of the Cistern

The same restraint is shown in the second figure, where the modeling of barrel vaults and arcs is also shown. In the detail we have realized the FEM model using bi-dimensional shell elements for walls, arcs and barrel vaults while the columns have been modeled with mono-dimensional finite elements, type frame.

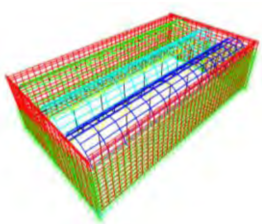


Fig.11-FEM structural model with all the structural elements

The next figure shows the zoom on the barrel vault and arch modeling. We need to explain that the filling load was applied considering a solid element representative of the granular material present on the barrel vaults. That choice is correct because the non-structural material is characterized by a unit volume weight but not by resistance parameter, therefore modeling of this element allows to consider in the analysis only the mass of filling material and to neglect the contribution of stiffness made to the structure.

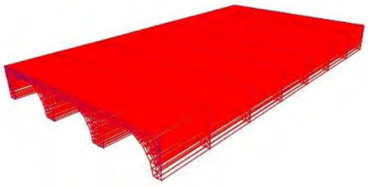


Fig.12. Representation of the filling element representative of the load applied at the structure

The seismic behavior was assess by carrying out a dynamic linear analysis of the structure, and evaluating periods and vibration modes in order to calculate the horizontal actions in the modal-spectral condition.

Regarding the modal structure behavior we have a first natural vibration period of 0,146s with a frequency of 6,77 Hz corresponding to the translation vibration mode in y direction, or rather in the more flexible direction .

In the following fig.13 we show modal response and vibration mode of structural elements in the modal condition case.

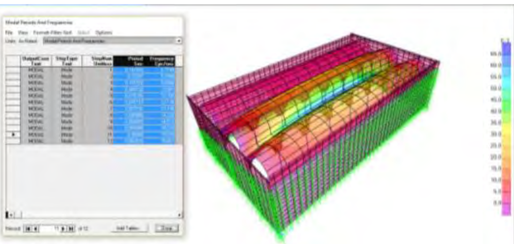


Fig.13. Modal response and vibration mode of structural elements

The analysis of structure behavior was conducted considering different load conditions. In the specific case we show the barrel vault response in seismic load condition, and the fig.14 shows the compressive stress S22 contour.

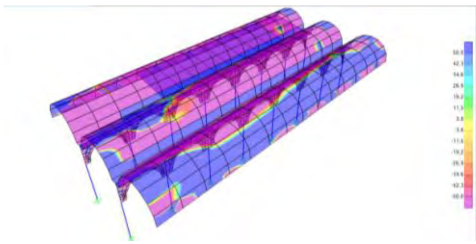


Fig.14-FEM structural model results for the Cistern's vault. Compressive stress S22

The contour represents the stress response of barrel vaults and arcs when we have the seismic load in the x direction, or else, in the axis of barrel vault direction and we can see that the stress of masonry element change in a range of +50MPa and -50MPa.

In this case, we propose images of the most burdensome load condition by way of example.

In the follow we will show the section cut in two different position of barrel vault, or in other words, in the two most important sections of barrel vault in terms of static structural behavior, then in the key section and in the impost section of considered element. The section cut allows us to evaluate the resultant forces in there section, integrating the stress.

The tables summarize the results for each section and for each barrel vaults in terms of horizontal, vertical forces and stress characteristic.

Table 3. Stress in the vault according to FEM Model

Position	Horizontal force [kN]	Vertical force [kN]	Resultant [kN]	σ [Mpa]
Key Block of vault	27,33	22,89	35,65	0,033
Impost Block of vault	20,00	50,00	53,85	0,2

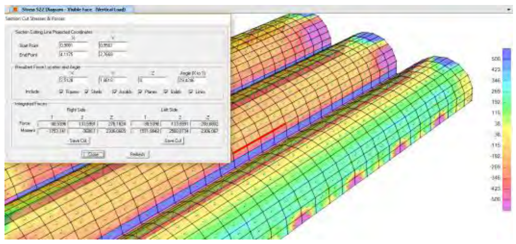
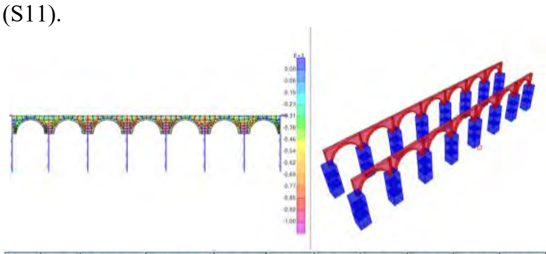


Fig.15 - Stress in the vault according to FEM Model

In this section we show the base reaction at the supporting restraint for each load conditions of columns that are mono-dimensional finite elements.

In the detail in the following tables we can see the values of axial force (P), shear force (V2,V3), bending moment (M2,M3), torsion (T) and the stress values (S11).



Frame	Station	OutputCase	CaseType	P	V2	V3	T	M2	M3	S11Max
53	1,45	Vertical Load	Combination	-120,665	1,03	50,442	0,1102	-71,6002	-1,3713	169,58
56	1,45	Vertical Load	Combination	-697,936	-0,108	11,3	1,0701	-16,0454	2,932	-418,78
59	1,45	Vertical Load	Combination	-819,385	-2,701	4,65	0,6112	-8,6932	8,4399	-509,53
62	1,45	Vertical Load	Combination	-860,147	-3,808	2,12	0,1747	-2,9701	10,7501	-549,68
65	1,45	Vertical Load	Combination	-855,392	-3,722	-2,07	-0,2197	2,7897	10,5695	-547,64
68	1,45	Vertical Load	Combination	-807,06	-2,501	-4,874	-0,617	7,0067	8,1085	-507,98
71	1,45	Vertical Load	Combination	-729,524	0,004578	-6,809	-1,0828	9,7544	2,9911	-462,36
74	1,45	Vertical Load	Combination	-119,932	0,972	-44,394	-0,094	63,9395	-1,3649	143,47

Fig.16 – Vertical Stress in the columns according to FEM Model

11. RESULTS AND COMMENTS

The structural stability of the historical cistern in Akkale has been analyzed in the following way:

- A simple numerical analysis, in the frame of the masonry analysis for arch, vault and cupola, in this case having the barrel vault and the arch as main important structural elements supporting the roof
- A more sophisticated Finite Element Analysis has been carried out in order to identify some specific behavior of the coupled barrel vaults and arches;
- One specific numerical analysis has been done on

some columns;
- An assess of the foundations has been performed.

The results of these analysis are quite encouraging, meaning that no specific critic section or structural element has been found during the numerical evaluation.

The investigation on site and in laboratory on similar material to that one existing in the Cistern gave some very positive results in term of resistance, confirming the comment done after the numerical analysis. No damage has been suffered by the monument during these investigations, since the only contact with the Cistern material has been done adopting Non Destructive Test, respecting the monument.

The safety factor which can be mentioned at the end of all the tests and analysis, if nothing special will happen to the structure in the near future, is quite high, we can state around "5".

12. RISK ANALYSIS AND SUGGESTION TO IMPROVE THE SAFETY OF THE STRUCTURE, SHORT AND LONG TERM

Not many suggestions could be given in order to improve the structure without suitable and further investigation on structural elements, material, soil. As previous stated, the structure appear quite solid, and light archaeological activities or investigation could be performed without particular precaution, in addition to typical reasonable precaution adopted in construction site.

In advanced step, when the cistern will be considered to be open to visitors, probably a deeper risk analysis should be performed.

From the report describing the analysis carried out on site as well as in the laboratory, it is clear that the material constituting the structure of the Akkale Cisterne can be considered a "good" construction material, with mechanic characteristic comparable with that of a good modern concrete.

At this point the only question arises about the amount of "local" damage of the structural elements, due to the intentional human vandalism, to the aging use of the structure or the atmospheric attack. This kind of damage in most of the case is visible, measurable but limited. In some rare point the damage is hidden (like in the bottom of some columns) since the visible part do not guarantee about internal, hidden, condition. Probably one deeper analysis could be a careful endoscopy investigation of some part of the bottom of the columns and other suspect masonry element.

Of course, now that we have more information about the existing material, after a deeper study and pondering on the possible local intervention on the stones, a reasonable static, and not only cosmetic, conservation solution could be found.

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