



2nd CISSET

Cilicia International Symposium
on Engineering and Technology
10-12 October 2019 MERSİN/TURKEY

PROCEEDINGS BOOK



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SYMPOSIUM ON
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(CISSET 2019)**

Proceedings Book

October 10-12, 2019

**Mersin University
Engineering Faculty**

Editor

Prof.Dr. Murat YAKAR

Assistant Editor

Assoc.Prof.Dr. Erdiñç AVAROĐLU

Assist.Prof.Dr. iĐdem ACI





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Paper ID	Title	Paper No.
2	Application of Discrete Controllers to a Pilot Scale Packed Distillation Column	1-5
3	Trend Analysis And Mapping Of The Black Sea Region	6-9
6	Long-Term Month Temperature Forecast With Inverse Distances Weighted, Kriging And Artificial Neural Networks	10-16
13	Ecosystems As Reservoirs Of Antibiotic-Resistant Bacteria	17-24
14	Determination Of Spray Angle In Sprayer Nozzles Using Computer Vision Technique	25-29
15	Comparison Of GPS-TEC With IRI-2007, IRI-2012 And IRI-2016 TEC Predictions At ISTA Station, Turkey	30-34
16	Dynamic Performance Comparison Of PI And Interval Type-2 Takagi-Sugeno-Kang Fuzzy Controller On Positive Output Luo Converter	35-39
17	Renewable Bio-Based Filler For EPDM Rubber: Indian Laura (Ficus Nitida)	40-43
18	The Application Of Waste Blue Crab Shell As A Bio-Based Filler In EPDM Rubber	44-48
19	Analysis Of Worth Assessment Of Information Sources Of Some Socio-Economic Characteristics Of Artisanal Fishers In Niger Delta	49-53
20	Low Velocity Impact Behavior Of Basalt/Epoxy Fiber Reinforced Composite Laminates With Different Fiber Orientation	54-57
21	The Implementation Of Real Time Window Functions On Field Programmable Gate Array	58-63
23	Ambient Particle Matter Pollution Near University Region Of Konya City	64-69
24	Physical, Chemical And Microbiological Qualities Of Potable Water Used In Different Poultry Farms A Review	70-73
26	Optimization Of Production Times Of Power Transformers Using Developed Artificial Bee/Ant Hybrid Heuristic Algorithm	74-77
27	Risk Assessment Analysis In Power Transformer Center In Erdemli District Of Mersin	78-81
29	Waste Management And Cost Analysis Of Construction Sites: A Comparative Study On Ankara (Bilkent) And Mersin City Hospitals In Turkey	82-91
32	The Production Of Novel Magnesium Alloys And Investigation Of Their Mechanical Properties	92-94
33	XAFS, A Powerful Technique For Electronic And Crystal Structure Analysis	95-97
34	Living And Working With Radiation	98-101

35	The Production Of Ni-Al Intermetallic-Reinforced Nickel-Matrix Composites From Ni-Al Powders	102-105
36	Graphene Produced With Using Surfactant From Expanded Graphite	106-109
37	Hydraulic Jump Energy Dissipation Evaluation In Rough Bed Channels Via Kernel Based Approach	110-114
38	Waste Almond Shell Reinforced Polydimethylsiloxane Rubber Composites	115-119
39	Waste Hazelnut Shell As A Bio-Based Filler In Polydimethylsiloxane Rubber	120-123
40	Microwave-Assisted Biodiesel Production From Oleic Acid	124-129
41	Electrical Conductivity Properties Of Cu-FeCr/FeB Composites	130-133
42	Upper Cretaceous Rudist-Bearing Limestones Of The Anamas-Akseki Carbonate Platform (Western Of The Central Taurides, Turkey)	134-137
43	Geodetic Studies On Producing Basemaps	138-142
44	Using The Geographic Information System Mersin University's Fiber Optic Network Construction Of Infrastructure	143-145
45	Investigation Of The Sensitivity Tolerance Paramater To Noise-Related Effect Using Sample Entrophy	146-149
46	Experimental Analysis Of Direct Shear Test For Dry Sand	150-154
47	Effect Of Grain Size Distribution Of Dry Sand	155-157
48	Evaluation Of The Zoning Peace Arrangement In Terms Of Content	158-162
49	Seismic Site Effects Of Soil Amplifications In Kahramanmaras Gayberli Neighborhood	163-167
50	Influence Of Doping On The Electrical Conductivity Of The Electrolytic Gels	168-171
51	Marble Potential Of The Mersin Region	172-176
52	Environmental Damages Caused By Open Cast Mines Exploitation In The Touristic Area Of Kruja, Albania	177-180
53	Effect Of Oriental Sweet Gum Oil (Styrax) On Characteristics Of Chitosan Cryogel Scaffolds	181-184
54	Design Of Macroporous Chitosan Cryogels Loaded With Green Synthesized AgNPs	185-189
55	The Production Of Ash-Free Coal By Solvent Extraction Method	190-193
56	An Analysis Of The Effects Of Feature Selection Methods In Classifying Turkish Hateful Messages	194-198

57	Fuel Properties Of Diesel Blended With Alternative Fuels	199-203
59	Phytoremediation Potential Of Lead By Rosemary (<i>Rosmarinus Officinalis</i>) Assisted With Citric Acid And Humic Acid In Contaminated Soil	204-209
60	Tensile And Flexural Characteristics Of Glass/Polyester Fiber Reinforced Composite Pipes Subjected To Different Loading Rate	210-214
61	Analysis Of Folds In Lower Devonian Sigircik Formation In Aydincik (Mersin) Area	215-219
62	Aluminum Brake Car Pedal Design, Production And Testing	220-222
63	Fiber Production From PLA/PU Blends By Electrospinning And Characterization Of Fibers	223-229
64	Synthesis And Characterization Of (Bimetallic Iron-Zinc Nanoparticles)/Carbon Composite Material For Naphthol Blue Black Decolorisation By Heterogeneous Fenton-Like Reaction	230-235
65	Avoiding Infinite-Precision Arithmetic For Bee Colony Optimization Algorithms: Cost-Based ABC	236-243
66	Honey Formation Optimization	244-250
67	Modeling Of Historical Fountains By Using Close-Range Photogrammetric Techniques	251-256
68	Anodic Oxidation Of Phthalic Acid In Extremely Acidic Medium In The Presence CrVI	257-261
69	Performance Comparison Of Reinforcement Learning Algorithms On Cart-Pole Control Problem	262-265
70	Effect Of Flight Height On Dem And Orthophoto	266-271
71	Availability Of Anafi Parrot In Disaster Site Modelling	272-275
72	Absorption Performance Of Nanopatterned AZO	276-279
73	AZO Metamaterial For Dual-Band Perfect Absorption	280-284
74	Absorption Characteristics Of 3D-Patterned AZO Nanoantennas	285-289
75	An Investigation Of Flotation Behaviour Of Silica Sands With High Iron Content	290-295
76	Effects Of Zircon And Corundum Based Additives On Technological Properties Of Wall Tile Engobes	296-300
77	A Review On Surface Chemistry Properties Of Zeolites	301-305
78	A Multiscale Entropy Based Approach For Analysis Of Surface EMG Signals	306-310
79	Design Of A Uniform Ice Cutting Device	311-317

80	Effects Of Weathering On Petrographic Properties Of The Basalts Employed In Diyarbakir City Walls	318-322
81	Design Analysis Of A Compound Fresnel Solar Concentrator (CFC) Using Ray Tracing Method	323-326
82	Comparison Of DC-DC Converters For Maximum Power Point Tracking In Photovoltaic Systems	327-331
83	Artificial Neural Network Implementation For DC-DC Converters In Solar Power Systems	332-338
84	The GUI Application For Calculating The Drag Torque In A Disengaged Multi-Disc Wet Clutch Using Multiple Models	339-344
85	Parallelization Of Dragonfly Optimization Algorithm On Distributed And Shared Memory Architectures	345-348
87	Investigation Of Mechanical Properties Of Geofom Materials Under Dynamic Loads Caused By Rock Fall	349-354
88	Numerical Modeling Of The Rockfall Induced Impact On Simply Supported RC Beams	355-358
89	Influence Of Coagulant Type In Removal Of Telon Red A2FR Textile Dye By Chemical Coagulation	359-363
90	Akkale Cistern In Mersin-Erdemli: Static Analysis And Risk Assessment	364-371
92	Application Of Supercritical Drying For Food Products	372-377
95	Bioclimatic Evaluations In The Mountainous Ecosystem Of Dajt: Case Study Tirana, Albania	378-382
96	Synthesis Of $\text{Co}_3\text{O}_4/\text{Fe}_3\text{O}_4$ Bimetallic Nanoparticles For Effective Adsorption Of Tetracycline	383-390
97	Robust Control Of Boost Converter Using Interval Type-2 Tsk Fuzzy Logic Controller	391-395
98	Production Of CoNiMnFe High Entropy Alloys With Mechanical Alloying	396-399
99	The Importance Of Historical Turkish Work Of Arts In Terms Of Engineering	400-403
100	About The Work And Map Of Mahmud Al-Kashgari	404-406
101	Some Applications Of Fibonacci Numbers In Apartments Modelling	407-411
102	The Classical Aes-Like Cryptology Via The Fibonacci Polynomial Matrix	412-416
103	Waste Mineral Oils Re-Refining With Physicochemical Methods	417-424
104	Radar Cross Section Analysis Of Unmanned Aerial Vehicle Using Predics	425-429

106	Treatment Of Barber Salon Grey Waste Water By Adsorption Process: Comparison Of Activated Carbon, Human Hair, And Basalt	430-435
108	Determination Of Marine Selection Criteria For Foreign Yachters By Ahp Method	436-441
109	Effects Of Salt On Human Health And Evaluation Of Rock Salt In Terms Of Medical Geology	442-445
110	Radar Cross Section Simulation And Analysis Of A Small Drone Model By The Help Of Predics Tool	446-450
111	Curvature Of The Triaxial Ellipsoid	451-456
112	Forward And Backward Problem On Triaxial Ellipsoid	457-463
113	An Analysis Of The Effects Of Environmental Factors On Vehicle Sales In Turkey Using Machine Learning Methods	464-467
115	Mechanical Properties Of TiC Reinforced Metal Matrix Composites Fabricated By Sand Casting	468-472
116	Production Of Ceramic Reinforced Aluminum Alloy Composite Materials: A Review	473-478
117	Kinetic Characteristic Analysis Of Elasto Caloric Copper Based Alloy	479-483
118	An Investigation Of Water Quality In Paradeniz Lake; Göksu Delta	484-492
119	A Critical Look Towards Design Of Anchored Retaining Walls In Accordance With Turkey's New Earthquake Design Code	493-499
120	An Investigation On The Geomechanical Properties Of Fiber Reinforced Cohesive Soils	500-503
122	Potentiometric Determination Of Acid Dissociation Constants Of 2-Iminothiazoles	504-509
123	PM Emission From Diesel Engines And DPF Technology	510-514
124	Anechoic Chamber Measurements For Circular ISAR Imaging At Mersin University's MEATRC Lab	515-518
125	Study Of Scattering Mechanisms Using Simulated Polarimetric ISAR Imaging	519-522
126	Effect Of Steel Fiber Addition On Abrasion Resistance Of Geopolymer Mortars	523-526
127	Influence Of Steel Fiber Addition On Drying Shrinkage Of Alkali-Activated Slag Mortars	527-530
128	Elevated Temperature Effect On Bond Strength Of Geopolymer Concretes	531-534
129	Investigation Of Fully Environmentally Friendly Waste Aggregated Alkali Activated Mortars	535-539
130	Production Of PVA/Chitosan Membranes As Tissue Engineering Scaffolds	540-543

131	Optimizing The Efficiency And Electricity Production Of An Internal Engine CHP Plant	544-548
132	Analytical And Numerical Modeling Of Heat, Fluid And Mass Transfer In Acetobacter acetii Liquid State Cultivation Bioreactor Integrated With Ground Source Heat Pump System	549-552
133	Design And Cost Analysis Of Solar Tower With The Capacity Of 20 MW In Mut District Of Mersin Province By Using Sam Program	553-557
134	Exact Solutions Of Klein-Gordon Equation With Position Dependent Mass And Magnetic Field	558-561
135	Geochemical Properties Of Salt Deposits Around Delice (Kirikkale)	562-564
137	Treatment Of Slaughterhouse Wastewaters By Fenton Process	568-572
138	Investigation Of Soil Properties In The West Of Erdemli (Mersin) District Center	573-575
139	Investigation Of Soil Properties In Old Mezitli Location Of Mezitli (Mersin) District	576-578
140	Analysis Of Static Output Measurements For Tomotherapy HDA	579-580
143	Design And Prototype Of A Slotted Waveguide Array Antenna For Marine Radar Applications	581-584
144	The Microplastic Debris Sink, Lakes; A Review	585-592
145	Classification Of Vehicle Models Using Deep Convolutional Neural Network And Transfer Learning Methods	593-597
146	Comparison Of Effect Of Absorber- Refrigerant Mixture For Cooling A Hotel In Mersin Province By Using A Solar Powered Absorption Refrigeration System	598-604
147	Removal Of Manganese From Groundwater By Preparation Hydroxyapatite From Fish Bone With Response Surface Methodology	605-612
148	Phosphate Removal From Groundwater With Hydroxyapatite Synthesized From Fish Bone Using Response Surface Methodology	613-619
149	Treatment Of Wastewater Resulted From Printing Processes In Corrugated Cardboard Production	620-624
150	Investigation Of The Activities And Kinetics Of Recombinant Bile Salt Hydrolases	625-628
152	Comparative Study Of The Use Of Two Irrigation Systems; Sprinkling And Drip On Soil Moisture And Quinoa Production In Ouargla Region-Algeria	629-635
153	Utilization of Food Waste	636-640
154	Effects Of Fat Content On The Textural Attributes Of Starch Paste Prepared In Milk	641-644
155	Roughness Coefficient Of Circular Channels With Smooth And Rigid Beds Via Evolutionary Algorithm	645-650

156	Drying Of Sludge By Heat, Case Study	651-654
157	Classification Performance Comparisons Of Deep Learning Models In Pneumonia Diagnosis Using Chest X-Ray Images	655-658
158	Effect Of Seawater Ageing On The Hardness Properties Of GFRP Composite Pipes	659-664
159	Clustering Network Traffic Records With K-Means Algorithm	665-668
161	Effect Of Seawater Ageing On The Mechanical Properties Of E-Glass Epoxy Composite Pipes	669-673
162	The Effect Of La (Lantanium) On The Microstructure And Mechanical Properties Of The High Pressure Die Cast Mg-4sb Magnesium Alloy	674-677
163	Comparison Of Regression Learner Methods For Daily Demand Prediction In Mass Meal Production	678-684
164	Daily Demand Prediction In Mass Food Production With Ensembles Of Trees Model	685-688
165	Approaches To Block VPN Applications	689-693
166	High Pressure Processing Of Foods	694-699
167	Magnetron Sputtered Cu_2SnS_3 Thin Films	700-702
168	Photoelectrical Properties Of Mo/N-Si Metal Semiconductor Contacts	703-705
169	Temperature Dependent Electrical Properties Of ZnO/P-Si Heterojunction With CdS Buffer Layer	706-708
170	Wave Energy: A Global Overview Of The Current State Of Established Companies	709-716
171	Zinc And Lead Recovery From Zinc Extraction Residue By Two-Stage Selective High Temperature-Pressure Leaching	717-722
173	A Smart Home System Developed Using Artificial Neural Network On Raspberry Pi	723-727
174	Development Of An Artificial Intelligent Based Smart Home System Using Naive Bayes Classifier	728-732
176	Influence Of Mn Doping On Optical Properties Of MgO Thin Films	733-736
177	Electrical Properties OF Sb:ZnO/P-Si Heterojunctions	737-739
178	An Overview Of Traffic Accident In Turkey: Statistics Of 2018	740-743
179	Thresholds For Pavement Surface Texture And Skid Resistance	744-749
180	Herakleia Karia Ancient Port City With Geoheritage Areas And Urban Geology-Latmos Geopark (Besparmak Mountains)	750-753

181	Estimation Of Voltage Stability In Power Systems Using Artificial Neural Networks	754-759
182	Solution Of Exam Scheduling Problem With Ant Colony Optimization: An Example Of Mersin University Engineering Faculty	760-764
183	Comparing Coast Lines Of Aydinlar Pond With Photogrammetric And Remote Sensing Methods	765-770
184	Modelling Of A Landslide Site With Satellite And Uav	771-775
185	Trigonometric Series Solutions For Static Analysis Of Simply Supported Beam	776-780
187	Fuzzy Neural Network Dc Voltage Controller Of Three Phase Shunt Active Power Filter	781-785
188	Antimicrobial Activity Of Laurus Nobilis Essential Oil On Escherichia Coli ATCC 25922	786-788
189	Speed Control Of Direct Torque Controlled Induction Motor Based On Type-2 Fuzzy Logic Controller With Elliptic Membership Function	789-794
190	Screen Conformal Lightlike Hypersurfaces Of Metallic Semi-Riemannian Manifolds	795-798
191	On A Study Of Screen Semi Invariant Lightlike Hypersurfaces Of Metallic Semi-Riemannian Manifolds	799-802
192	Some Azomethins And Oxazolidines Synthesized Based On 2-Amino-4-Arylsubstituted Thiazoles	803-808



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 aqueducts 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 galleries (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 aqueducts until the port settlements of Elauissa/Sebaste and Korykos located in the west (Bildirici, 2009). This water system has seven aqueducts 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. Archaeological 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 (Aydmoglu, 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 m³ (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 clad with cut stone pavements, remains of which can be seen today.

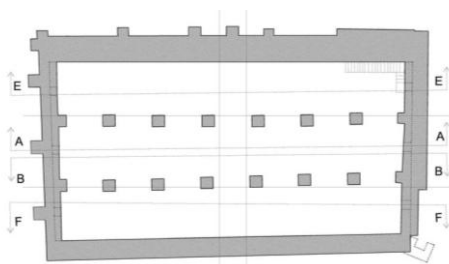


Fig. 2 – Plan of the Cistern

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

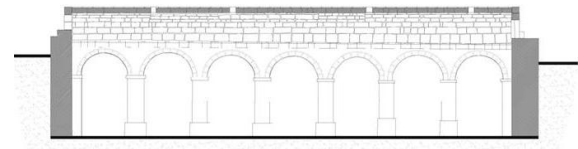


Fig.4 - Longitudinal cross section of Cistern

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:

- 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.
- to assess static conditions of the existing structure (cistern without water), related mostly to the surrounding conditions offered by the terrain and soil characteristics.
- 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.

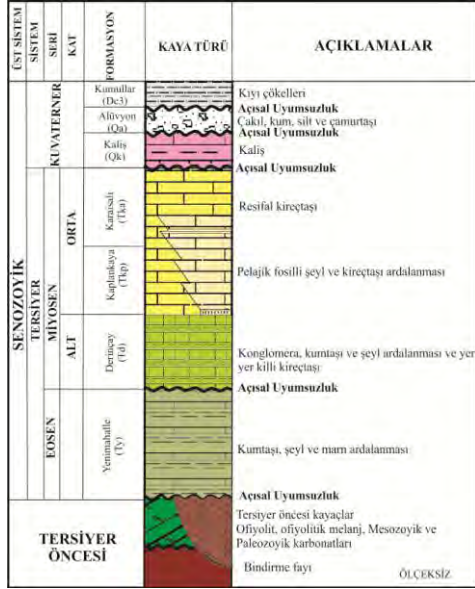


Fig. 5. Simplified stratigraphic section of soil in Akkale (extract from Güler&Tağa, 2018)

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 Schmidt 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 (σ_c , 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 (ν) 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&Tağa, 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&Tağa, 2018)

Sample name	σ_c 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 % (Auriscchio 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:

$$\eta := \frac{M_S}{M_T} = 1.136$$

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).

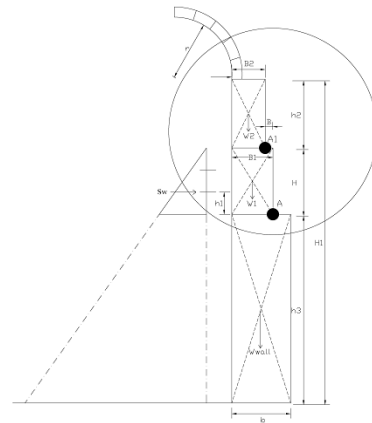


Fig.7- Water pressure diagram and vault thrust on the Cistern wall

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:

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

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

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

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

Rotation around "A" without water pressure

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

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

$$\eta := \frac{M_S}{M_T} = 1.541$$

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:

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

And if F_{cd} , 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.

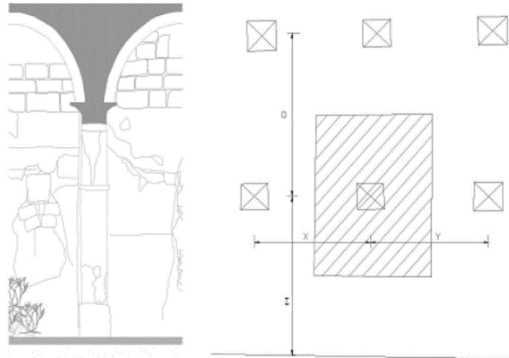


Fig.8 – The analysis of a typical central column

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 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.

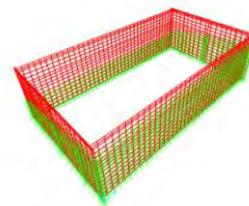


Fig.10-FEM structural model for the only wall of the Cistern

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.

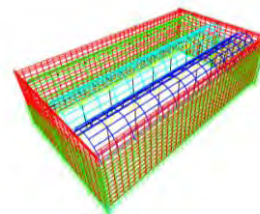


Fig.11-FEM structural model with all the structural elements

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.

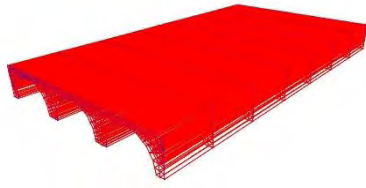


Fig.12. Representation of the filling element representative of the load applied at the structure

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.

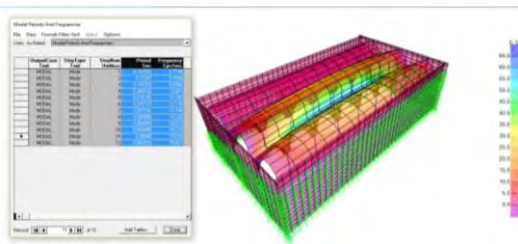


Fig.13. Modal response and vibration mode of structural elements

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.

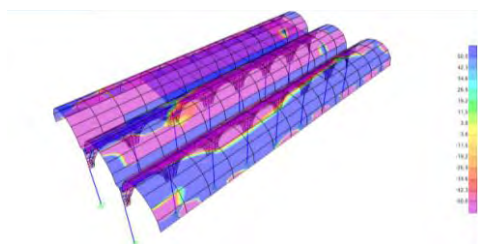


Fig.14-FEM structural model results for the Cistern's vault. Compressive stress S22

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]	Resultan t [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

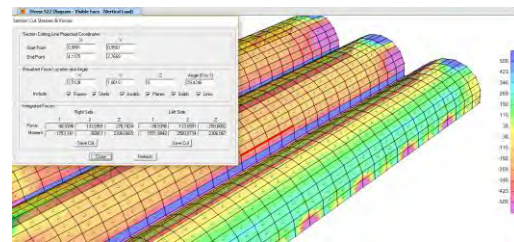
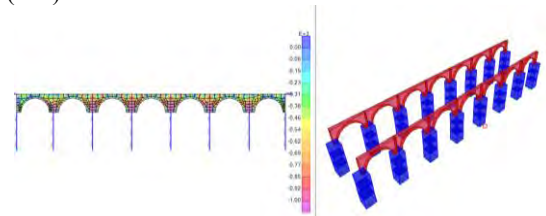


Fig.15 - Stress in the vault according to FEM Model

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	-505,53
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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REFERENCES

Abruzzese, D., G.Lanni. (1998). "On the strength of historical reinforced masonry buildings with crossed vaulted floors" *Proc. XI ECEE*, Paris

Abruzzese, D., G.E. Cinque, G. Lo Gatto. (2004). "Analysis of a Roman masonry flat-slab in Hadrian's Villa, Tivoli" *Proc. "Structural Analysis of Historical Constructions"*, University of Padova

Auriscchio, S.; Evangelista A.; Masi P. (1982). "Il tufo giallo napoletano: permeabilit ed impregnabilit con monomeri acrilici." *Rivista Italiana di Geotecnica*, Roma

Aydinoęlu, U., (2017). "Archaeological Report, Feasibility Research for Survey" *Conservation and Presentation of Akkale (Erdemli) Archaeological Sites*.

Akgl, Z. (1980). "The Basilica Cistern, (Istanbul)" *Aytur Turistik Yayincilik*, Istanbul

Bildirici, M., (2009). "Tarihi Su yapıları -Konya Karaman Nięde Aksaray Yalva Side Mut Silifke", *T.C. evre ve Orman Bakanlıęı Devlet Su İřleri Genel Mdrlę*, Ankara, 486-487.

Borel, L., C. March, S. Desoutter. (2007). "El Nabih Cistern" *Centre d'Etudes Alexandrines, in Alexandrie, Mtaphore de la francophonie*

Como, M. (2016). "Statics of Historic Masonry Constructions" *Springer Series in Solid and Structural Mechanics, Springer*

Gueguen, Philippe. (2013). "Seismic Vulnerability of Structures" *John Wiley & Sons, Inc.*, London

GLER, C., H. TAęA,(2018). "Akkale (Erdemli-Mersin) ren yeri Byk Sarnı Yapısı ve Civarında Gerekleřtirilen Jeolojik-Jeofizik alıřmalar" *Scientific Report*, Mersin, 27 February 2018

Haselberger, L., R. Holod, R. Ousterhout, (2016). "Against Gravity" University of Pennsylvania

Koyuncu, I.; Altınbas, M.; Aydın, A.F.; Guclu, S.; Turken, T.; Ecis, R.; Yıldız, A.; Tutuncu, H.. (2012). "Nomad Cisterns in Antalya, Turkey" *Proceedings of the 3rd IWA Specialized Conference on Water and Wastewater Technologies in Ancient Civilization*, Istanbul, Turkey, 22-24 March

Mays, L., G. P. Antoniou, A. N. Angelakis. (2013). "History of Water Cisterns: Legacies and Lessons" *Water, Vol.5, Issue 4, Nov. 2013*