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## Geotechnical investigation for determination of causes for occurred deformations of the Skopje Aqueduct

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### ABSTRACT

*This paper deals with geotechnical investigation works for assessment of factors which led to occurrence of deformations of Skopje Aqueduct – significant monument for Macedonian cultural heritage.*

*The period of construction of the Aqueduct is still undetermined. According some data, the monument was built in the 6th century in the time of the Byzantine emperor Justinian I, while according to other data, it was built in the 15th century. It is presumed that it was still in use by the end of the 19th century.*

*Based on the performed geotechnical investigations and geophysical surveys on the site, emphasizing the deformed zone of the Aqueduct, as factors for occurrence of deformations were noticed the relatively weak stress-strain properties of the foundation soil, the shallow foundation of the structure, the permanently flooded site, local tectonic and the modifications in the spreading of surface clayey layer, as possible agents for different damaging (sloping) of the Aqueduct pillars.*

**Keywords:** Aqueduct, geotechnical investigations and geophysical surveys, deformed zone

\* presenting author

## 1. INTRODUCTION

The Aqueduct is located on the north of the city centre between the Skopje Fortress – Kale and the Skupi archaeological site, in vicinity of the city of Skopje, Republic of Macedonia. As a linear building with an angle in the center of the construction, the Aqueduct is a distinctive landscape feature.

It is built over a small valley of the Serava River, with the altitude close to 300 meters, as a part of water supply system that carried water from Skopska Crna Gora Mountains to Skopje Fortress.

The construction date of the Aqueduct is still undetermined. *According some data, the monument was built in the 6<sup>th</sup> century in the period of Roman or Byzantine Empire i.e. the time of the Justinian I (527-554 A.D.).* But due to similarities in the construction method between this structure and Kurshumli An in Skopje it is considered that the Aqueduct is built in the 15<sup>th</sup> century, period in which the city of Skopje intensively started to grow along with building of new Islamic structures – Turkish baths and mosques. For construction and functioning of such facilities huge quantities of pure water were required. It is presumed that it was still in use by the end of the 19th century.

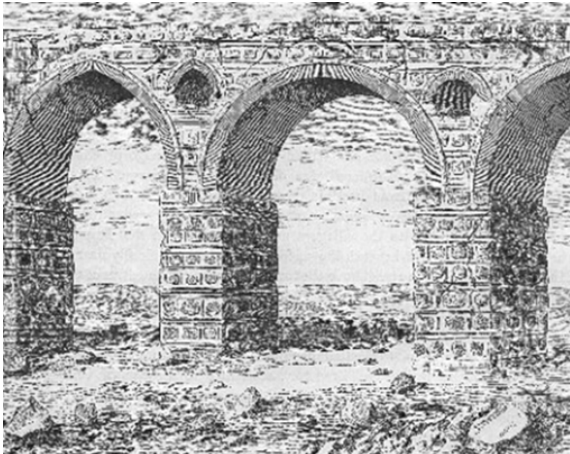


Figure 1. The oldest overview of the Aqueduct in Skopje, drawing from year 1883-1884 (published by the English archaeologist Arthur John Evans, 1885)

Overall, the Aqueduct have a double role - construction with strictly defined function

into water supply system, and at the same time with high architectural values.

### 1.1. The Aqueduct construction generals

The Aqueduct is preserved in its entire length which is 385,80 meters long, and it has 54 main vaults and 42 so called “relaxing” vaulted holes placed over the pillars for reducing the structure weight. The lower part of the Aqueduct consists of 53 square or rectangular pillars whit width of 2,15 meters to 2,24 meters, and 2 side ramps – northern and southern, with their foundations.

Method of building is rich and colourful, from different kinds of stone and brick. The pillars from the oldest construction phase are built of river stone in characteristic rows of brick old format and partly stone tiles and other fragments in lime mortar. The facades are of mixed masonry, stone and brick in lime mortar, with archivolts and outside arches of brick. The Aqueduct as original civil structure, provides the opportunity to studying the methods and techniques of building this type of construction and used building materials.

Few construction phases and repairs can be noticed on the building. Most of those originate from the end of 19<sup>th</sup> century and the beginning of 20<sup>th</sup> century. After the Second World War, three vaults were destroyed by mines in a military exercise to demonstrate the destruction of bridge vaults. It is presumed that these vaults were reconstructed in 1968 yr.



Figure 2. Aqueduct after the dynamites' exercise

The last restoration of the Aqueduct was carried out after the earthquake in Skopje in 1963, repairing three arcs and two pillars destroyed due to the earthquake activity.

In the central part of the Aqueduct the construction is not vertical, it is with an inclination to the west which is up to 53 cm, and there is a very serious problem of disturbance the stability and demolition the section between pillars no. 9 and pillars no. 15.

Also, a part of the foundations are threatened by high groundwater level, so in rainy periods form small swamp at the lowest point along the construction.

Special threat to the monument is a risk of earthquakes. The Skopje valley is a seismically active zone. The estimated risk indicates a risk of earthquakes from 7 to 9 degrees by MCS (risk area of 9 MCS is located at the bottom of the valley).

The aim of this paper is to present the performed geotechnical investigations, which would determine the causes of occurred deformations of construction, as well as to recommend appropriate activities for its remediation.



Figure 3. Panoramic view of the Aqueduct in Skopje

## 2. GEOTECHNICAL INVESTIGATIONS

In March 2014 yr. by the company "Geing Krebs und Kiefer International" Ltd Skopje, was performed field investigations and laboratory testing on the location of the Aqueduct. They are performed according to methodology which is in accordance with the technical norms widely applied in Macedonia and in foreign countries, the Macedonian standards as well as the instructions and recommendations from the technical literature.

The purpose of performed investigations and testing is determination the lithological structure, with specifically defining the physical - mechanical and stress - strain properties of soil materials, for determination the reason of occurred deformations, as well as establishing the appropriate activities recommended for remediation of the object.

For more detailed presentation of the lithological structure on the location were applied the following investigation works:

- Engineering - geological and hydro - geological site mapping;

- Performance of geophysical seismic investigations;
- Performance of investigation boreholes;
- Standard penetration test – SPT test for each borehole;
- Mapping of the investigation boreholes;
- Measuring and registering the appearance and level of groundwater;
- Performance of trail pits;
- Sampling non-disturbed, semi-disturbed and disturbed samples from the investigated boreholes;
- Trail pits mapping;
- Cone penetration test – CPT test;

### 2.1. Engineering - geological and hydro - geological site mapping

The terrain is composed of younger proluvium deposited sediments, composed of sands and gravels, silty gravel, covered with clay ( $Q_{2pr_{sk}}$ ). The thickness of these sediments is 5÷10 m;

Under the proluvium sediments there are Pliocene sediments composed of sands and gravels, silty clayey, marls, sandstones and conglomerates to depth

of 60.00 m. Under these sediments there are Miocene - Pliocene marl sediment deeper than 1000 m.

The geological investigations on the terrain are showing that there is fault with direction NE-SW. This profile is not given on the engineering-geological map for Skopje, but is given on the engineering-geological profiles VIII-VIII' and XII-XII' (in the mentioned report from 1963-1964). It is estimated that this fault cuts the location on the damaged part of the aqueduct.

## **2.2. Performance of geophysical seismic investigations;**

The seismic investigations are performed with shallow refraction and reflective profiles, placed according the investigation purposes.

The refraction profiling are performed with 4 profiles with total length of 325 m. The profile RF-1 is performed with length of 125 m on distance of 1m (east) from the pillars' line of the aqueduct, continuously along the complete length on the investigated location. The profile RF-2 is made at the beginning, RF-3 in the middle (zone of modification of the pillars inclination) and RF-4 at the end of the investigated location. These profiles are performed normally on the line of the aqueduct pillars, each with length of 65 m. The profiles are performed with geophone distance on 5 m and stimulation of seismic waves on 15 m.

For more detailed perception of data modification from refraction investigations it is performed refraction interpretation of reflective profiles, given in the refraction profiles RF-5 (located in parallel with RF-1 on distance of 5 km toward west) and RF-6 located in parallel with RF-3 on distance of 4 m toward north. The complete length of these profiles is 190 m.

With the refraction profiles is reached depth of 20-30 m.

The reflective profiling are performed in order to provide comparison if the interpretation of the geological structure from refraction surveys with surveys with

higher resolution. These surveys are performed with continuous following of the litho-physical modifications in the ground and noticing the local tectonic properties of the location. The surveys provide more realistic defining the data for physical – mechanical and the geotechnical assemble of the investigated area.

For registering seismic waves are used vertical geophones of 14 Hz.

## **2.3. The interpretation of data from refraction profiles**

The interpretation of data from refraction profiles is performed with hodochrones of P and S waves, thus were determinate the following parameters of registered elastic environments:

- The values of  $V_p$  and  $V_s$  seismic velocities;
- The physical-mechanical and elastic dynamical properties, determinate according the seismic  $V_p$  and  $V_s$  velocities;
- The dynamical properties of materials during earthquake;

The refraction survey determinates the following contoured and average (in the bracket) values of seismic waves  $V_p$  and  $V_s$  of the foundation environments of the aqueduct and its geological basis.

- High plastic clay, on depth of 1-3 m with values of  $V_p=340-450$  (400) m/s and  $V_s=125-180$  (150) m/s;
- Sands and gravels, silty clayey materials on depth of 2-5 m and values of  $V_p=400-550$  (500) m/s and  $V_s=180-250$  (220) m/s;
- Sands, gravels, sandy clayey silt on depth of 8-12 m with values of  $V_p=910-1360$  (1100) m/s and  $V_s=400-570$  (460) m/s;
- Sands, gravels and clayey silt on depth of 8-23 m, with  $V_p=1750-2350$  (2000) m/s  $V_s=650-950$  (800) m/s;
- Sandstones, marlstones and conglomerates deeper than 23 m, with  $V_p=2420-2760$  (2600) m/s and  $V_s=1000-1100$  (1000) m/s.

The first three environments belong into Quarter younger proluvial sediments ( $Q_{2pr_{sk}}$ ), and the average 4 and 5 of Pliocene sediments (PI). We should stress out that some of the materials in the middle 3 belong into the surface weaken Pliocene materials.

According the data of refraction profile RF-1 and RF-5, the deeper depth of Quarter proluvial sediments (around 12 m) are in the beginning – the north part of the location (the pillars S1, S2 and S3) near the channel Serava. At the final – south part of the location (S20 and S2) its depth is around 6-8 m. Comparing the data from the profiles RF-1 and RF-5 (on distance of 5 m), we can conclude that the depth of the quarter sediments is reduced for around 2 m in the west part, actually for the same distance is increased in the east part of the location.

This conclusion is confirmed with the cross section profile RF-2 and RF-6. On the profile RF-3 is obtained increasing of the thickness at the Quarter sediments in the west part, and on the profile RF-4 in the east part of the location. The appearance of RF-4 can be explained with possible surface or tectonic damaging of the surface Pliocene sediments.

According the values of seismic waves, the first elastic environment – the surface layer with depth of 2-3 m can be classified as archeological cultural layer.

#### The interpretation of reflective profiles determinate:

- Elastic litho-physical boundaries between the surface clay layer and proluvial sandy gravel material and between the materials of proluvial and Pliocene sediments;
- The tectonic disturbing and dislocation (faults) in geological environment of the terrain;

From point of view the local tectonic here are interpreted two tectonic dislocations, cutting the investigated location of the aqueduct. The first dislocation ( $P_1$ ) has spreading NW-SE and cuts the aqueduct in the zone of the third and the fourth pillar. This dislocation is agent for the inclination of the pillars (1-9) of the aqueduct toward east in the first half of the location. The second dislocation ( $P_2$ ) has direction NE-SW, cutting the zone in the tenth and eleventh pillar causing inclination of the pillars (10-21) toward west in the second part of the location. The dislocation ( $P_2$ ) is confirmed with the geological investigations after Skopje earthquake in 1963-1964.

The interpreted local tectonic and the modifications for spreading the surface clay layer are the possible reason for the variable damaging (hobbling) of the aqueduct pillars. Due to this it should pay attention to the modifications of the physical – mechanical properties of the clay during the different weather conditions and the effects of clay swelling.

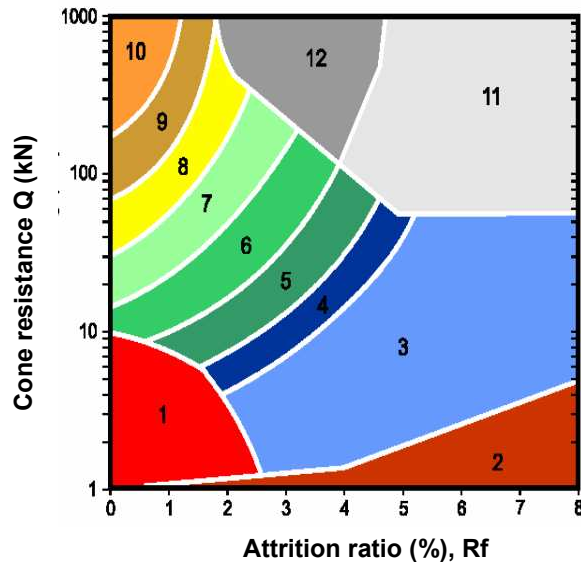
Table 6. Interval values of elastic dynamical parameters

Parameter	Proluvium sediments ( $Q_{2pr_{sk}}$ )	Proluvium sediments ( $Q_{2pr_{sk}}$ )	Proluvium sediments ( $Q_{2pr_{sk}}$ )	Pliocene sediments (PI)
H (m)	1-3	2-5	8-12	25-60
V <sub>p</sub> (m/s)	340-450	400-550	910-1360	1750-2750
V <sub>s</sub> (m/s)	125-180	180-250	400-570	650-1100
γ (kN/m <sup>3</sup> )	15-16	17-18	19-20	21-23
μ <sub>din</sub>	0.42-0.40	0.38-0.37	0.38-0.39	0.42-0.40
E <sub>din</sub> (MPa)	68-148	165-315	855-1840	2570-7950
G <sub>din</sub> (MPa)	25-55	60-115	375-660	905-2840
K <sub>din</sub> (MPa)	142-247	230-405	1100-2790	5350-13250

## 2.4. Cone penetration test – CPT test;













On the investigated location are performed tests of static penetration (CPT – test). The test of static penetration is performed with penetrometer type Holland 10 t with cone Type: Dutch Mantle Cone D=35.7 mm, A=10 cm<sup>2</sup>. The measurements are performed in the following phases:

- Cone resistance;



- Resistance of pipe attrition;
- Resistance of attrition of cone and pipe;

The classification of soil materials is performed according the recommendations of Robertson et al, 1990 which is showed in following pictures and tables.

Zone		
1		Sensitive, fine grained
2		Organic materials
3		Clay
4		Silty clay to clay
5		Clayey silt to silty clay
6		Sandy silt to clayey silt
7		Silty sand to sandy silt
8		Sand to silty sand
9		Sand
10		Gravelly sand to sand
11		Very stiff fine grained*
12		Sand to clayey sand*

\* Over consolidated or cemented

Table 7. Classification of soil materials

Depth [m]	Mv [kN/m <sup>2</sup> ]	Classification <b>Robertson (1990)</b>	Description <b>Robertson (1990)</b>
<b>CPT-1</b>			
0.25-2.00	4500	CI/MI	Clay
2.00-2.50	17700	ML	Very compact, fine grained, over consolidated or cemented materials
<b>CPT-2</b>			
0.25-1.75	6500	CI/MI	Clay
1.75-2.50	12000	ML	Very compact, fine grained, over consolidated or cemented materials
<b>CPT-3</b>			
0.50-3.00	4300	CI/MI	Clay
3.00-3.75	12000	ML	Very compact, fine grained, over consolidated or cemented materials
<b>CPT-4</b>			
0.25-3.50	2618	H, CI/MI	Clay, organic clay, humus
3.50-4.00	57750	CI/MI	Clay
4.00-8.50	16125	SFs	Very compact, fine grained, over consolidated or cemented materials
<b>CPT-5</b>			

0.75-1.00	750	H	Organic materials
1.00-2.50	8250	CI/MI	Clay
2.50-4.00	12375	ML	Very compact, fine grained, over consolidated or cemented materials
4.00-4.50	37500	SFs	Very compact, fine grained, over consolidated or cemented materials
<b>CPT-6</b>			
0.00-1.00	300	CI/MI	Clay, organic clay
1.00-3.25	3000	CI/MI	Clay
3.25-4.00	52500	SFs	Sandy silt to clayey silt
<b>CPT-7</b>			
0.25-1.00	1750	CI/MI	Clay
1.00-2.25	39300	SFs	Very compact, fine grained, over consolidated or cemented materials
<b>CPT-8</b>			
0.25-0.75	1500	CI/MI	Clay
1.75-1.50	65000	SFs	Very compact, fine grained, over consolidated or cemented materials

**2.5. Performance of investigation boreholes;**

On the investigated site are performed 10 (ten) investigation boreholes, each with 10.00 meters depth. The investigation drilling is performed with two drilling machines (GAK 300 and GDR 150) on previously defined locations marked from

BH-1 to BH-10. The investigation drilling is performed geomechanical point of view, with dry drilling that allow getting quality core 100%.

The data for the depth of the investigation boreholes, type, number and depth of each sampling, as well as the ground water appearance are given in table no. 8.

Table 8. Review of investigation boreholes

Borehole	Final depth [m]	Appearance of groundwater	Level of groundwater Sampling	Sampling
BH-2	10.0	/	/	3
BH-3	10.0	6.30	/	3
BH-4	10.0	/	6.30	4
BH-5	10.0	/	8.30	4
BH-6	10.0	/	6.30	6
BH-7	10.0	8.30	/	2
BH-8	10.0	8.30	/	4
BH-9	10.0	/	/	3
BH-10	10.0	/	/	2

During the investigation drilling are performed SPT tests, for quality estimation of the foundation compactness. The tests are used for orientation qualification of the mechanical parameters of the materials ( $\phi$ ,  $c$  and  $M_v$ ) as comparative indicators of

the laboratory tests. The compression module for the incoherent materials is determinate through the SPT (Standard penetration test) in table no. 9.

Table no. 9 Review of performed SPT tests

Borehole	Depth	Cone penetration (cm)	Hits number N	Corrected number of hits				Compactness/c onsistency	Compressibility modulus Mv (kPa)	Angle of internal friction $\varphi$ (°)
	(m)			N'	N''	N <sub>kor</sub>	N <sub>def</sub>			
BH-1	1.600÷1.904	30.4	29	20	/	/	20	Solid	12500	/
	3.800÷3.900	10	30	21	/	64	64	Very compact	48300	43
	7.700÷8.004	30.4	21	15	/	/	15	semisolid	10000	/
BH-2	1.700÷2.004	30.4	30	21	/	/	21	solid	13000	/
	3.200÷3.330	13	30	21	/	49	49	compact	37800	40
	5.200÷5.504	30.4	14	10	/	/	10	semisolid	7500	/
	7.500÷7.804	30.4	17	12	/	/	12	semisolid	8500	/
BH-3	2.300÷2.450	15	30	21	/	43	43	compact	33600	39
	4.000÷4.210	21	30	21	/	30	30	medium compact	24500	36
	6.200÷6.504	30.4	13	9	/	/	9	semisolid	7000	/
BH-4	8.500÷8.804	30.4	26	18	/	/	18	medium compact	16100	33
	1.600÷1.904	30.4	27	19	/	/	19	solid	16800	/
	2.600÷2.770	17	30	21	/	38	38	compact	30100	38
	4.800÷5.104	30.4	11	8	/	/	8	soft	6500	/
	7.000÷7.230	23	30	21	/	28	28	medium compact	23100	36
BH-5	8.000÷8.210	21	30	21	/	30	30	Medium compact	24500	36
	2.200÷2.504	30.4	30	21	/	/	21	solid	13000	/
	5.000÷5.280	28	30	21	/	23	23	solid	14000	/
BH-6	7.800÷8.104	30.4	24	17	/	/	17	medium compact	15400	32
	1.800÷2.104	30.4	22	15	/	/	15	semisolid	10000	/
	3.500÷3.804	30.4	24	17	/	/	17	semisolid	11000	/
BH-7	7.200÷7.504	30.4	20	14	/	/	14	semisolid	9500	/
	1.700÷2.004	30.4	30	21	/	/	21	solid	13000	/
BH-8	7.000÷7.240	24	30	21	/	27	27	medium compact	22400	35
	1.600÷1.880	28	30	21	/	23	23	solid	14000	/
BH-9	1.500÷1.630	13	30	21	/	49	49	compact	37800	40
	5.600÷5.840	24	30	21	/	27	27	medium compact	22400	35
BH-10	1.500÷1.804	30.4	13	9	/	/	9	semisolid	7000	/
	5.000÷5.304	30.4	15	11	/	/	11	semisolid	8000	/

## 2.6. Physical-mechanical features of the materials and its classification

In order to obtain more representative physical – mechanical properties of the terrain depending on depth, it were performed certain type and scope of investigations boreholes from which were taken representative samples for further

laboratory testing, i.e. defining the physical – mechanical properties of the present materials on the field and the location under the aqueduct.

According the performed classification based on the site mapping and the laboratory tests we can conclude that on the mentioned location there are the

following types of materials with physical – mechanical properties as given bellow.

**Surface layer of clays – CI/MI**

This material is registered on the terrain surface along the complete profile on the investigated location with maximal layer thickness of 3.00 m. This layer is composed of medium plastic silty clays in semi-solid to solid consistent condition and covered with humus layer with maximal thickness of 1.00 m. The physical – mechanical properties are given as it follows:

$\rho$ Mg/m <sup>3</sup>	$\varphi$ [°]	c kPa	Mv kPa
1.81	16.3÷16.6	13.8÷15.0	7400

**Silts and silty sands – ML, CL/SFs, SFs/ML, SFs**

These materials are registered under the surface layer of clays. They are classified as low plastic silts, clayey and silty sands and sandy silts. The physical – mechanical properties are given as it follows:

$\rho$ Mg/m <sup>3</sup>	$\varphi$ [°]	c kPa	Mv kPa
1.81	16.3÷16.6	13.8÷15.0	7400

**Silts and silty sands – GP, GFs**

In the lower layers on the location to the final depth there are materials like low grained and silty sandy medium to well compact gravels.

$\rho$ Mg/m <sup>3</sup>	$\varphi$ [°]	c kPa	Mv kPa
1.8	16.3÷16.6	13.8÷15.0	7400

**3. CAUSES FOR APPEARANCE THE DEFORMATIONS OF THE FACILITY**

Based on the performed geotechnical and geo-physical investigations on the location, with special review of the deformed zone of the Aqueduct we can conclude the following:

The aqueduct is founded on foundations with average width of 2 x 2 meters in the layer of silty clay with medium plasticity, and foundation depth of 0.70 meters to 1.30 meters from terrain elevation.

As reasons for appearance the deformations of the Aqueduct are the following:

- The local tectonic and the modification in the clayey surface layer are the possible reason for the variable inclination to the west which is up to 53 cm. Thus, it should pay attention to the modification of physical – mechanical properties of the clay during different weather conditions and to the effects of clay swelling;
- The relatively low deformable properties of the soil layer where is the foundation (especially during presence of water);
- The relatively shallow foundation of the facility;
- Constantly flowing terrain (creation of “lakes” and swamp zones)

**4. CONCLUSIONS**

Although the Aqueduct in Skopje is not generally known and appreciated by the public, the consensus is growing that the Aqueduct and its surrounding area are unique and have an important historical, architectural and esthetical value.

From geological point of view the terrain on the investigated location is composed of quarter sediments represented with clayey silty fraction creating the upper layers and silty sand and gravel, partially clayey deposits in the lower layers. Under the Quarter sediments there are Pliocene sediments composed of sands and gravels, silty clayey, marls, sandstones and conglomerates to depth of 60 meters and under that there are Miocene Pliocene marl sediments on depth of 1000 meters;

From hydro-geologic point of view the investigated site belongs into the group of low to well yield terrains where is developed compact type of aquifers in sediments characterized with inter granular porosity. Considering the geological structure of the field, especially the upper parts, we should stress out on the location and the wider region is

present contemporary geologic process of permanently washed terrain (creation of "lakes" and swamp zones);

From geo-tectonic point of view the investigated location belongs into area with maximal intensity of VIII and IX° according MCS. The strongest earthquake is noticed in 1963 with intensity of IX° according MCS in Skopje epicentre area, followed with aftershocks with own local epicentre on depth of 5 km;

On the location are performed 10 (ten) investigation boreholes each with depth of 10.00 meters, 8 (eight) tests of static penetration SPT-tests, 8 (eight) trial pits near the most damaged pillars and geophysical seismic survey with total length of 325.00 meters, refraction surveys and 180.00 meters reflective surveys;

The location has relatively heterogeneous composition concerning the classification and physical – mechanical properties of the present materials. The surface layer is composed of silty sandy medium plastic clays covered with humus and clayey humus cover. The maximal spreading depth of the layer is 3 m. Under this layer to the final investigation depth there are sandy silts, silty sands and gravels, as well as low grained gravels in the zone around river Serava;

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## **REFERENCES**

Geing Krebs und Kiefer International Ltd Skopje (2014) "Elaborate for geotechnical investigations and laboratory testing on the location of the Aqueduct in Skopje".

Ministry of Culture, Skopje (2011) "Strategic plan for preservation and

rehabilitation of the Aqueduct in Skopje and its environment".

Master Urban Plan Skopje, Institute of town planning and architecture – Skopje; Polservice Consultants, Warsaw; Doxiadis Associates – Consultants on Development and Ekstics, (1965)

Lenche Jovanova, "Skupi – Colonia Flavia Scupinorum", Skopje (2008)

Kosta Balabanov, Antonie Nikolovski, Dimitar Kjornakov, "Monuments of culture in Macedonia", Skopje (1980)