SURVEYING THE EUPALINIAN AQUEDUCT IN SAMOS ISLAND

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KEY WORDS: Surveying Monuments, Laser scanning, Documentation and Monitoring of CH

ABSTRACT:

In this paper the effort of surveying the Eupalinian Aqueduct is presented. This detailed survey has been carried out during spring 2009 in the framework of a study in order to restore it and make it available to the general public. Several methods have been used for the survey such as classic topographic using precise total station, GPS measurements and laser scanning. The final results are plans in 2D & 3D and virtual models. The Eupalinian Aqueduct is a remarkable water pipeline created 2500 years ago. Its main section is the tunnel of Eupalinos described by the ancient historian Herodot. Due to his description the tunnel was looked for and discovered in the last century. The German archaeological Institute, free-vacated and investigated the entire plant in early ’70s. The antique water pipeline has its beginning beyond the city wall mountain at a spring in the village Agiades. From there it leads the ridge on a length crossed by 900 m underground up to the north slope of the mountain, in a tunnel of 1036 m length and runs further 500 m at the south slope to the city side into a well house. The entire water pipeline is a technical masterpiece of first rank adopted by UNESCO as a World Heritage Site. The tremendous achievement, which the construction of this plant means, can be appreciated most simply by numbers: For the inlet approximately 1500 m^3 grown rock, for the tunnel with the channel approximately 5000 m^3 had to be dug and for the city line again 500 m^3. All these works were accomplished with hammer and chisel, other aids were not available. We can only roughly estimate how long it took for this construction. However for the tunneling through the mountain, at which locally only two laborers could work at a time, eight years is a fair guess, so for the entire scrapings probably it took almost ten years. The tunnel lies at 55 m above sea level approximately and thus 180 m under the summit. It has an average cross section of 1,80 m to 1,80 m and runs, with small deviations, horizontally. The channel, in which the pipeline was sited, has a 4 m depth at the north entrance of the tunnel and more than 8 m at the south exit.

  

1. INTRODUCTION

When Polycrates was tyrant in Samos, which was influential shipping and trading centre in Greece, three major works are constructed. One of them was the aqueduct; the other was the Hera temple and the port. It was a great technological Πρόκειται για σπουδαίο τεχνολογικό achievement which was described in Herodotus scriptures. Due to that description it was possible to discover and excavate it. There is no other scripture for this and probably we could never find it if there was not this description from Herodotus. Following this description, the French archaeologist Victor Guerin, arrived in Samos in 1853 looking for the tunnel. He localizes the spring and the beginning of the aqueduct but he did not discover the tunnel. Afterwards more people were looking for it until 1882 when a monk revealed the tunnel and there was an effort for re-operation, but it was abandoned because it was difficult to clean it. In 1884, the German archaeologist Ernst Fabricius, investigate the tunnel as long as it was possible at that time and he marks its place in a map of the British Admiralty (fig. 1). 90 years later, Ulf Jantzen, director of German Archaeological Institute of Athens, wanted to continue the work of Fabricius, thus in 1971 they began the excavations that lasted more than two years. Afterwards the cleaning and the study of work assigned to the German archaeologist Hermann Kienast who published his conclusions in 1995.

Figure 1. Illustration of the aqueduct by Ernst Fabricius in 1884

The tunnel was the more important part of work for water supply of the city. It is a tunnel of 1036 meters. It was manufactured in 530 b.C. as Herodotus informs us engineer of the work was Eupalinos from Megara, son of Naustrophos. In the written sources it is reported that between the 56 students of Pythagoras, as long as he was living still in Samos, was also someone Eypalinios. Considering that this name was not very spread, we can suppose that Eypalinos was already in Samos as a student of Pythagoras, when the work was entrusted to him. Consequently it is very likely that the great philosopher and his schoolteacher has helped him and inspired him for the difficult manufacture.

2. DISCRIPTION OF THE WORK

The aim of engineer that undertook the work, Eypalinos, was to create a tunnel through the mountain Ampelos so that he could bring the water in the city of Samos, which today is named Pythagorion. The spring of Agiades was found behind the mountain Ampelos in the north-west of the city. It had allowance of 400m^3 per day and it was shaped from the antiquity in order that the water gushes out through the natural rock. It had been covered in order not to locate and also the altitude of her level was in 52 meters. The engineer of work should have accomplished to supply the city water from the source of Agiades, the pipeline was underground, through the mountain, so that it was not localized from by any chance enemies and the orifice that flows in the city should be found inside the walls and in altitude that would ensure the effortless flow in all the city.

The possible ways of the pipeline were perimetrically the mountain, with surface ditch, or underground under the mountain with tunnel. Eupalinos chose the second solution. What led him to this solution, if he followed the first, then, because of the total length of the pipeline and the hydraulic bent, the water would reach the city in lower altitude and would have problems in the flow to the houses. The reasons that led him to his manufacture were the water shortage, the weakness of satisfaction of needs in water from wells and the guarantee of water supplies in the siege event.

Eupalinos constructed 870 meters of covered pipeline from the spring until the mountain (fig. 2), in undergrounds of builder ditch, afterwards 1036 meters in the tunnel, which was opened in the mountain and finally 520 meters from the mountain in the reservoir of the city, again in ditch. The tunnel was manufactured horizontally, (for the fear of underground waters) and straight, (in altitude of +55.8 meters from the sea level). It has been constructed amphistomous, (excavated simultaneously from both edges, for saving of time) and afterwards constructed a ditch along the floor of the horizontal tunnel, through which the water was channeled in the reservoir of the city with earthen half pipes. The horizontal tunnel with a length of 1036 m. begins from northern side of mount Ampelos, (nowadays Castle), and leads to the southerner. It was founded 180 m. under the top of the mountain. The tunnel has orthogonal cross-section with dimensions 1.80 x 1.80 m. In the tunnel and in-depth 3.5-8.5 meters was created a channel with the pipeline with bent 0.6% that transported the water in the city. This manufacture proves the high level of knowledge and the way of confrontation of problems that had the engineers of the 6th century b.C. For this construction they were essential knowledge of mathematics, geometry, topography and geodesy. Even today constitutes feat a work as and this, much more in his season with the means that had in his disposal, (Eupalinos).

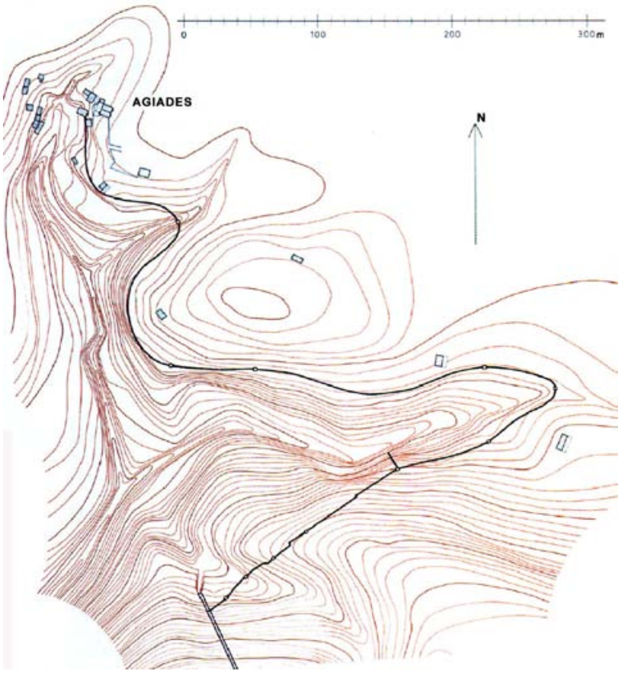

Figure 2. The pipeline from the spring up to the tunnel

3. EUPALINO'S ACHIEVEMENTS

Eupalinos had faced many topographic difficulties during the construction, these were:

- The determination of the two tunnel edges in the two slopes of the mountain, so that they are situated in the same altitude
- The determination of direction of excavation with which they should enter in the mountain from both the two edges
- The accomplishment of the pipeline way of the water with the bent that he chose, (0.6%), in the bas-relief of the ground.

There are visible even today the controls, the daily measurements and the modifications, indelible engraved in the rock of underground work. He used the letters of alphabet in order to mean in the rock characteristic places and levels. The observer who wishes he can find in the conclusions of Kienast a lot of important details that are not present here.

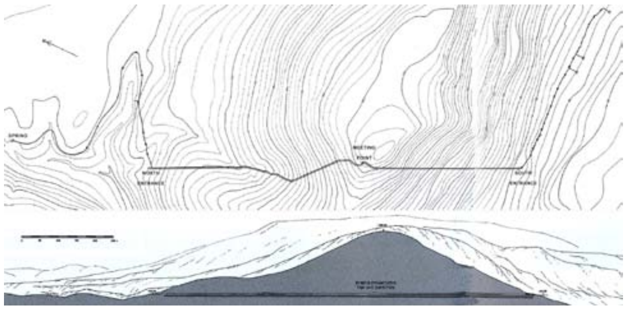

Figure 3. Plan and section of the pipeline from the spring to the city

In order to met the two working groups, that had begun 10 years ago the excavation of the tunnel, they had to face the hard limestone but also some unexpectedly, as the cavity, they met excavating from the northern sector which was forced to change his course, following this cavity. They dare the simultaneous excavation from two foreheads, they succed the meeting of the two groups with minimal divergence, they inventive the inclined channel for the placement of earthen half pipes and they precise the single bent 0,6% at length of the entire pipeline. Moreover technical achievements are:

- the process of control for the simultaneous excavation by two foreheads
- the meeting the two excavating groups with so much small divergences for that time and the means they had
- the excavation of the inclined ditch into the main tunnel
- the keeping of single bent 0.6% in all the length of the pipeline

Eupalinos achieved the meeting of the two sectors with small fault of direction 0.64^{o} in the northern tunnel. However in order to be certain that they will be met he raised the roof of northern tunnel in the last 27 meters and he increased the declivity of flooring of southern tunnel in the last 25 meters so that he extended the forehead of meeting. Afterwards, it was proved that even if he did not make this, the meeting of the two foreheads would be also met with a minimal divergence, for that time, of order of 28 cm.

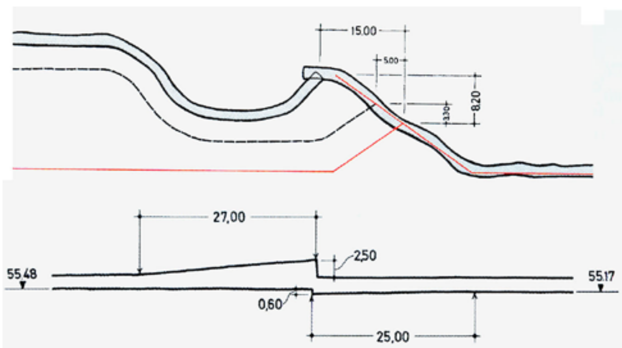

Figure 4. Plan and section of the meeting area

The divergence from the ideal point of meeting was 15 meters in length and 8.2 meters in width (fig. 4). However with a carefully observation, we will conceive that he decreased the total work of two groups in that way.

4. EUPALINO'S METHODS

Eupalinos had faced several problems and we wonder about the methods and the instruments he could use to achieve the precisions that we reported before. Still all relative details have not been answered from scientists who work and have spent many years in this study. However there are discoveries which testify some techniques as an example the setting out of the direction of the tunnel in the southern side, where in the 40 m from the entry there was found a vertical well which was dug in order to control the direction (fig. 5).

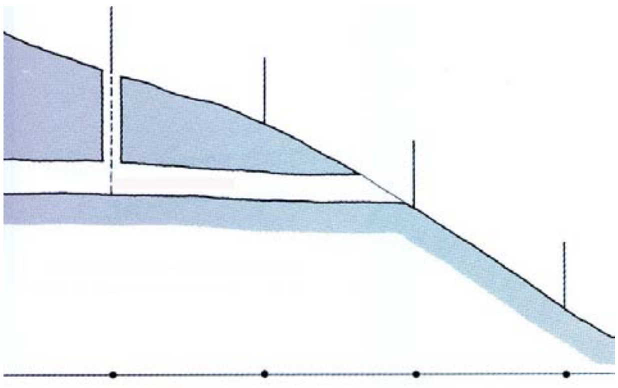

Figure 5. Control of the direction of the tunnel

In order to determine the horizontal level we believe that he used an instrument, known at that time, the level, (chorovati) (fig. 6), with that he determined the horizontal level using boards driven in the ground in such a way that their top materializes the horizontal level.

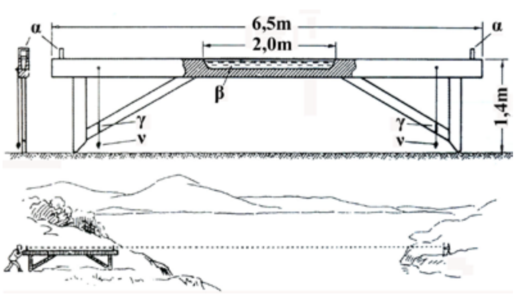

Figure 6. The level

Certainly he used the diabetes, an instrument which was known at that time and it helps for the setting out and for the localization of bents but we are not sure if he used the dioptra of Heron of Alexandrea, (a kind of theodolite).

Eupalinos achieved for the first time in the history of humanity to construct such a work. He organized and executed his drawing with absolute precision. Finally he celebrated his success writing indelibly in the point of meeting the word PARADEGMA, (example), with letters of 30 cm height and his name remained in the history.

5. THE SURVEY OF THE AQUEDUCT

In spring of 2009, there was a survey for the aqueduct. In the beginning we establish a control network using GPS. They have been used dual frequency geodetic receivers by Trimble. After that we did a survey using reflectorless total station on the surface of the ground and underground also. The instrument we used was a Leica TS09 with one second accuracy for the angles and 2mm accuracy for the distances. The main traverse through the tunnel has more than 65 stations with a total length more than one kilometer and with a closure error of 10 cm. We survey cross sections every 10 meters and we marked those points.

We did a survey with laser scanner also but we did it only for 800 meters because after that the tunnel was too narrow for the scanner to work. From this survey we develop a 6 minute walk through from which someone can have an idea for the situation of the tunnel. The problem was that the available scanner by Optech, had a cut off distance of three meters and for this reason there are many "holes" in the end product.

From the survey we draw plans of the tunnel, isometric views of both sides of it and a plan for the roof, than we did the surface topographic plan and the longitude section, and cross sections every half meter. We also did the map of the parts of the aqueduct from the spring till the tunnel and after the tunnel till the reservoir in the city. The survey last for twelve days while we were two groups one with the total station and the other with the laser scanner. For the manipulation of the data we needed about two months.

Simultaneously with the survey there were geologists who did geological surveys with magnetometers and resistivity meters to determine cavities and water reservoirs behind the walls and the interior of the tunnel. Also rock engineers observed and measured the unstable rocks in order to maintain the tunnel. And civil engineers who will make the final proposition for the tunnel. Using the drawings they will make a project for the restoration of the monument in order to make it visitable for the people.

6. CONCLUSIONS

This aqueduct, older than 2500 years, has been adopted by UNESCO as a World Heritage Site. We feel lucky that we had the opportunity to enter in the same galleries with the builders and we could see and feel their efforts and their achievements. There are still frescos visible on the rock walls of the construction telling us their fight against the mass of the rock to find their target. But finally they succeed and they did it in a great way. Now we feel obliged to them that we have to restore and make known this master piece of work and give it to the public as it should be because it belongs to the world heritage.

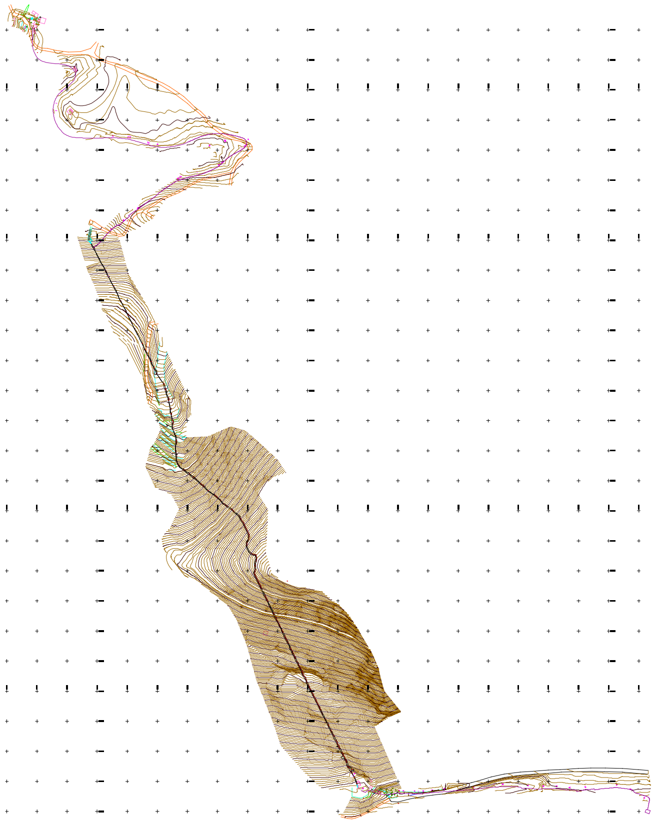

Figure 7. The plan of the aqueduct, (grid=50m)

ACKNOWLEDGEMENTS

I want to thank all the people that have helped in any way to complete this effort. Starting from the staff of Egnatia Odos SA who had the idea to start this project, the local authorities in Samos, the fellow-workers from department of geology under prof. G. Tsokas, the fellow-workers under the master of the project K. Zampas. I want also to thank all my staff starting from my son P. Tokmakidis, the architect R. Yoshitake from Japan and my ex students K. Andritsos and P. Polyzos.

REFERENCES

Kienast H.J., Die Wasserleitung des Eupalinos auf Samos, Samos XIX, Deutsche Archäologische Institut Athens, 1995

Kienast J. Hermann, The aqueduct of Eupalinos in Samos, Ministry of Culture TAPA, Athens 2004

Tokmakidis K., Vlachos D., The Eupalinos tunnel, Scientific Meeting "The Development of the Instruments, of the Methods and of the Measuring Systems in Survey Sciences in Greece", Thessaloniki April 15-16, 2005