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Pepouza (Clandras) Water Conveyance System

Ahmet ALKAN

Department of Civil Engineering, Dokuz Eylül University, Buca-İzmir, Turkey
Corresponding author's E-mail: *ahmet.alkan[at]deu.edu.tr*

Abstract: ***Turkey is one of the foremost open air museums of the world with respect to historical water works. The Pepouza (Clandros) water conveyance system, at the Banaz (Sinderos) tributary of the Büyükmemderes River, is a newcomer of this museum. The remains include that of the Clandras aqueductbridge and several stretches of rock-cut and/or masonry open canals. The total length of the water conveyance is in the order of 4.2 km.***

Keywords: Water Conveyance History Canal Aqueduct Bridge

1. Introduction

The three substances necessary for human life are air, water and soil. With the transition from the Prehistoric age to the Neolithic age, the water need of the increasing population has also increased. They used existing water resources to meet their growing water needs.

Structures like well, cistern, water tank, spring water collection chamber, weir, dam, were used to collect and store water. Elements like pipes (terra cotta, stone, lead, wooden), open channel (earth, masonry), covered gallery, underground tunnel, pressure pipe inverted siphon or arched aqueduct-bridge to cross the valleys, were used in the conveyance and distribution. Anatolia was at the crossroads of several civilizations during the last 4000 years, where a great variety of hydraulic structures were implemented, making Turkey one of the foremost open air museums of the World in this respect [12, 62, 66-68, 70, 71, 72].

Magnificent examples of water conveyance systems, dating back to the early centuries of the Ist Millenium A. D. are encounteredin Turkey.

Among these systems, special interest deserve those of İstanbul [20, 21, 22], Parion [42, 43]; Pergamon [28, 29, 33-35]; Troia [41]; Phocea [10, 59]; İzmir [27, 58, 64, 74]; Ephesus [32, 46, 63, 69, 78-83]; Aphrodisias [19, 24]; Alabanda [5, 60, 61]; Laodicea [8, 9, 76, 77]; Mylasa [2, 3]; Patara [7, 11, 37]; Antiochia ad Pisidia [13, 14]; Perge [6, 15, 16]; Aspendos [15, 16, 44, 45, 47, 54]; Side [15, 36, 38]; Elaiussa Sebaste, Olba, and Diocaesarea (allthree in in Lamas basin) [4, 21, 40, 51-53, 55-57]; Antiochia ad Orontes [25, 48, 73]; Samosata [39, 62]; Amaseia [50]; Ankara [31].

Compared to these renowned historical water conveyances, that of Pepouza (Clandros) is rather a very modest, but charming example added to the distinguished open air museum of ancient water works in Turkey.

2. Location

The aqueductbridge Clandros, apparently the only one of the water conveyance system, is located roughly 30 km to the southeast of the province center Uşak, crossing the Banaz (Clandras) tributary of the Büyükmenderes river. The system probably supplied water to the antique city Pepouza, roughly 3.5 km to the southwest of the village Karayakuplu, and has been constructed during the Roman period.

3. Remains of Water Works

The conveyance system is basically a rock-cut and/or masonry open canal, between the source in the east and the settlement Pepouza in the west; its layout is given in Fig.1.

Two springs, one at the right bank (Fig.2; spring on Fig.1), the other at the left bank, fed the water conveyance. The one on the right bank supplies actually the village Karayakuplu; the other, on the left bank, is extinct, covered by the Karahallı water power plant.

The conveyance canal, along the northern right bank of the canyon, is mainly rock-cut, partly masonry (Fig.3). The canal from the left bank spring crossed the Banaz creek on the Clandras aqueductbridge, partly damaged (Fig.4; point 2 on Fig.1). The conveyance continues along the northern right bank of the canyon (Fig.5; point 3 on Fig.1). There is a section with two roughly parallel canals, probably due to the bypass of a ruined part of the conveyance (Fig.6; point 4 on Fig.1). Further evidences were encountered at several downstream locations (point 5 to 16 on Fig.1).

Two villages, Kavaklı and Hasköy, are actually supplied with water, conveyed from a spring near point 16 on Fig.1.

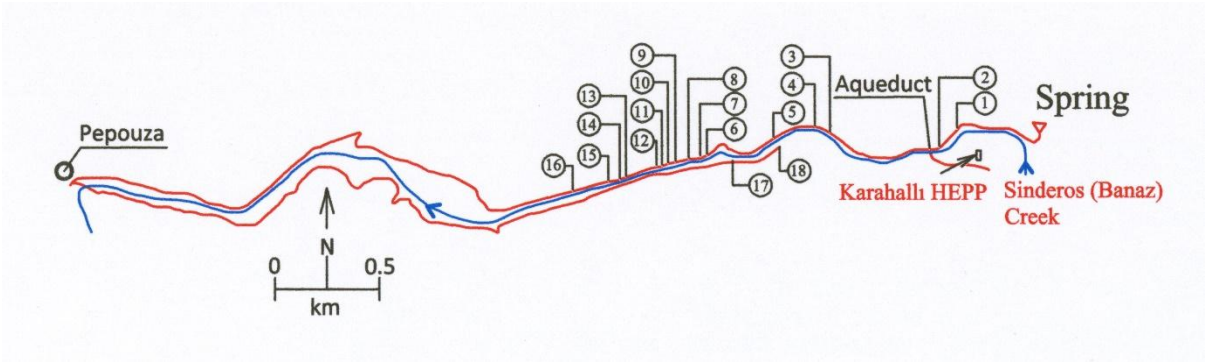

Figure 1: Ancient water coneyances to Pepouza

Figure 2: At the right bank spring

Figure 4: Clanrasaqueduct bridge and remains of rock-cut canal

Figure 3: Rock-cutcanal at point 1 on Fig.1

Figure 5: Rock-cut canal section at point 3 on Figure 1

On the left bank, quite downstream of the disappeared spring, there are certain remains of similar canals (Fig.7), probably belonging to a shorter, left bank conveyance to Pepouza. Further remains of the conveyance were

encountered at two downstream locations (point 17 and 18 on Fig.1).

Figure 6: Two roughly parallel canals at point 3 on Figure 1

4. Hydraulic Capacity under Free-Flow Conditions

The conduits of ancient water conveyance systems are generally baked clay pipes, rock-cut or cut-and-cover masonry galleries and tunnels. The water is usually carried under free-flow conditions, yet, in certain pipe systems, it sometimes flows under pressure.

An analysis of the system for free-flow conditions, i. e., open-channel flow induced by gravity [16, 17, 30, 49, 69, 75] is based on the Manning equation (called also Gauckler-Manning-Strickler equation) for uniform flow. The equation is derived from the Brahms-Chézy formula and introduces a friction factor as a function of the hydraulic radius:

$$v = (1/n).\ R^{2/3}.\ J^{1/2} \quad (1)$$

In this equation, v is the mean flow velocity (m/s), n is the Manning roughness coefficient, R is the hydraulic radius (m) of the wet cross-section, and J is the energy gradient practically equal to the slope of the conduit. The hydraulic radius is the ratio of the wet cross-section area A (m^2) to the total length of the wet contours (m).

Introducing discharge Q (m^3/s) as the product of the velocity and of the wet cross-section (Q = v. A), the Manning equation can be developed as:

$$Q = (1/n).\ A.\ R^{2/3}.\ J^{1/2} \quad (2)$$

The flow regime related to a certain water depth in a conduit of prismatic shape is evaluated through comparison with the critical depth for the given conditions. This comparison is based on the following equation:

$$A^3/B = \alpha.\ Q^2/g \quad (3)$$

in which B (m) is the width of the water surface, α is the energy correction factor, and g is the gravitational acceleration (m/s^2).

The water depth resulting in the equality of both sides of the equation is the critical depth. If the left hand side is larger, the regime is subcritical. If the right hand side is larger, the regime is supercritical; and any increase in hydraulic losses may cause a hydraulic jump and a sudden increase in water depth, eventually creating problems.

5. Hydraulic Capacity of the Water Conveyance System

The elevation of the initial spring at the right bank is 681.6 m asl.; the length of the conduit between the spring and the Clandras aqueduct bridge is around 450 m. The elevation of the modern pump station (point 16) is 651.6 m asl.; the conduit length between the aqueduct bridge and the point 16 is around 1500 m.

Hence, between the source and the point 16, the elevation difference is 30 m and the total length 1950 m, corresponding to an average gradient of 0.015 (or 1.5 %). The length difference between point 16 and the settlement Pepouza is 1800 m, so the anticipated total length of the conveyance is 4200 m. It was assumed that the gradient would be in the same order along the last part of the conveyance.

The width and height of the conduit with a rectangular cross-section varies along the conveyance, with widths of 0.35 to 0.5 m, and heights of 0.4 to 0.8 m, and even higher at rock-cut sections.

For a cross section with 0.35 m width and 0.40 m height, the smaller values encountered, and considering a Manning coefficient of friction of n = 0, 035, the estimated hydraulic capacity corresponds to roughly 0.12 m^3/s (120 lt/s).

The remains of the shorter conduit along the left bank of the Banaz creek, have a rectangular cross-section of 0.8 m width and 0.4 m height; it was not possible to identify an alignment, thus to calculate a meaningful hydraulic capacity.

6. Conclusion

The ancient water conveyance to Pepouza, southeast of Uşak, along the right bank of the Banaz (Sinderos) creek in the upper part of the Büyük Menderes basin, is basically a rock-cut or masonry open channel of roughly 4.2 km length, with a capacity exceeding 100 lt/s. It constitutes a newly discovered element of the large open-air hydraulic structures museum formed by Turkey.

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