EVALUATION OF HISTORICAL WATER WORKS IN TURKEY FROM HYDRAULIC ENGINEERING POINT OF VIEW

Akif Ozkaldi[1], Huseyin Akbas[2], Koksal B. Celik[3]

ABSTRACT

The main objective of this article is to analyze the primary historical water works constructed in Turkey throughout the four thousand years from hydraulic engineering point of view. Since the subject is too extensive, the article is only focused on historical waterworks in Turkey from Hittite, Urartu, Hellenistic, Roman, Seldjukide, and Ottoman periods.

In the first part of the study hydraulic structures from Hittite period are presented. The earliest remains of water works in Turkey dated from the Hittite period, primarily the second millenium B.C. It is believed that the most ancient dam in Anatolia (a part of modern Turkey) is Karakuyu dam constructed for irrigation purpose.

In the second part of the article water works from Urartians are discussed. The Urartians (one of an early eastern civilizations) was an early leader in complex irrigation networks. The most important water works of the Urartians is Samram irrigation canal, dating from 800 BC.

Hellenistic, Roman and Byzantine water works are presented in the following part of the article. Water conveyance systems to Side, Pergamon, Ephesus, Aspendos, Laodecia, Perge, Istanbul etc. exhibit great richness, variety and important engineering skills.

In the last part, water structures of Seldjukide and Ottoman periods are investigated. Bridges of Seldjukide period are important engineering and architectural structures. Halkali, Kirkcesme, Uskudar, Taksim water ways of Istanbul, Taslımusellim waterway of Edirne, dams of Istanbul, flood protection canals, aqueducts, water mills, water balance towers of Ottoman period respect special attention from hydraulic engineering point of view.

1- Chairman, Project and Construction Department, General Directorate of State Hydraulic Works, Ankara-Turkey.
2- Deputy Chairman, Project and Construction Department, General Directorate of State Hydraulic Works, Ankara-Turkey.
3- MSc in Civil Engineering, Project and Construction Department, General Directorate of State Hydraulic Works, Ankara-Turkey.

1. INTRODUCTION

Turkey, the cradle of civilization throughout the mankind history, deserves special attention because of its historical hydraulic structures. Numerous pipelines (terra-cotta, stone, lead), canals, tunnels, inverted siphons, aqueducts, galleries, reservoirs, settling tanks, wells, cisterns, and dams of Turkey exhibit a fine sense of the hydraulic technology of their times.

2. WATER WORKS DATED FROM HITTITE PERIOD

Hittites constructed several hydraulic storage structures in central Anatolia since water resources were scarce in the region.

After a serious drought period Hittite King Tudhaliya IV ordered numerous dams to be built in Anatolia in 1240 BC. One of them is the dam in Alacahoyuk, Corum called Golpinar Dam. The water source is inside of the dam's reservoir. The Hittites used this dam to provide irrigation and tap water. In Hittite period tap water from this dam was collected in a sediment settlement pool, after the pool they conveyed water by using a two km long pipeline. After a recent restoration it stores 15000 m^3 of water and is still used for irrigation.

Karakuyu, the most ancient dam in Anatolia, was constructed for irrigation of Uzunyayla region. The U-shaped crest of the dam has a total lenght of 400 m. The upstream slope of the dam appears to be covered with a stone pavement (Ozis, 1999). Eflatunpinar Dam near Beysehir, Koylutolu Dam near Ilgin, Golpinar Dam near Corum, Guneykale Dam at Bogazkale, spring collection chamber in Bogazköy are the other important Hittite hydraulic structures. Hittites also constructed terra-cotta water conveyance pipelines especially in Bogazkoy. The lenghts of the terra-cotta pipes vary from 0.60 m to 0.96 m. Their diameters gradually vary from 20–22 cm to 11–15 cm having conical shapes.

3. WATER WORKS DATED FROM URARTU PERIOD

The first irrigation canals, reservoirs and dams in eastern Turkey (which lies in a region subject to violent sismic activity) were constructed by Urartians in the first half of the first millenium BC. Urartian hydraulic engineers had precautions to build eartquake resistant structures some of them are still in relatively good condition after thousand years.

Tushpa (Tuspa), shore of Lake Van became the capital of Urartu Kingdom about 830 BC. Since the water of Lake Van is not suitable for drinking (because of high sodium carbonate concentration) they built a conveyance canal from Engil (Hosap) Creek to Tushpa for the water supply of the city and agricultural purposes (Garbrecht, 1985).

The oldest large-scaled conveyance system in the world seems to be the Urartian Menua channel which was constructed around 800 BC by King Menua (810-786 BC) (Fahlbusch, 2000). This 56 km long water canal conveyed 2-3 m^3/s of water from Engil (Hosap) creek springs to Tushpa (Vankale) region. The widht of the canal varies from

3.5 to 4 m and the depth of the canal varies from 1.5 to 2 m. The source of the canal lies at an altitude of 1760 m, and the altitude of the downstream of the canal is around 1700 m.

A level route for the Menua canal has been created by building high retaining walls along valleys and low depressions. The retaining walls of Gulo Bogazi and Kadembasti have 11-12 m heights. Nearly half of the Menua Canal (23-25 km of its total lenght) has been carved out of rock. (Belli, 1997).

Another remarkable example of the Urartian's hydraulic engineering skill is Ferhat Canal, which has been supplying irrigation water in the vicinity for 2700 years without interruption. The width of the canal varies from 2 to 2.5 m and the depth of the canal varies from 1 to 1.5 m. Its capacity is lower than Menua Canal but it has been cut into the bedrock in planes where the terrain forms an obstacle like Menua Canal.

In order to supply water to the later Urartian capital city, Rusahinili (Toprakkale) the storage capacity of Rusa (Kesis) Lake has been increased by the construction of two dams around 700 BC (Ozis, 1999).

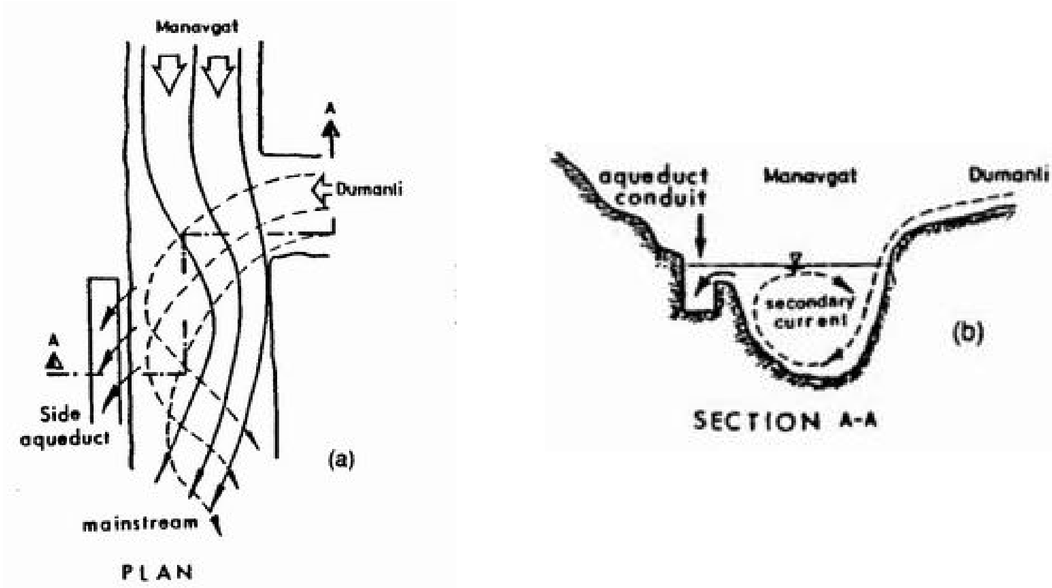
4. WATER WORKS DATED FROM HELLENISTIC, ROMAN, AND BYZANTINE PERIODS

4.1. SİDE WATERWAY

Side Waterway is an important example of antique hydraulic engineering. This water conveyance system is especially unique because of the engineering technic had been used on intake structure.

Roman engineers supplied water from Manavgat (Melas) River right after Dumanli-Manavgat River junction (35-40 m downstream of the junction) by the help of a side weir situated opposite side of the junction (Hodge, 1992).

Dumanli Spring is a steep sloped river with a mean discharge of 50 m^3/s. Roman engineers prefered this location for side weir in order to derive high quality water of Dumanli Spring. They diverted 400-500 lt/s of discharge by means of this hydraulic structure. The side weir typed intake structure is a good example of the Roman engineers observing river currents and profiting from them. Following the side weir typed intake structure the 25.3 km long Side water conveyance system includes 24 aqueducts, several tunnels, galleries, and inspection manholes. Tunnels have widths of 2.05-2.70 m and heights of 1.85-2.05. Closed canals at the beginning have widths of 1.10-1.30 m. The slope of the conduit is around 0.1 %. 19th km of the system there was a branch for irrigation. Antique Side city had also used groundwater and precipitation water by the help of cisterns and wells besides the Side water conveyance system.



Figure–1: Side side weir (Hodge, 1992).

4.2. EPHESUS WATER CONVEYANCE SYSTEMS

Ephesus city deserves special place in the history of water resource engineering. Ephesus has been supplied by water through four important water conveyance systems, two of them were exceeding 40 km lenght. These are Sirince, Derbentdere (Marnas), Degirmendere (Kenchrios), Kayapinar (Kaystros) water conveyance systems.

The Sirince water conveyance system consisted of terra-cotta (baked clay) pipes. Total lenght of the system is 8 km long. The inner diameters vary between 10 and 16 cm, and outer diameters vary between 12 and 22 cm. It mainly collects the groundwater. It is probably dated to 6th century BC but it had several repairs throughout the centuries.

Derbentbere (Marnas) water conveyance system is 6 km long, conveying springwater from southeast of Ephesus through three parallel terra-cotta pipelines. The first pipeline crossed the Marnas valley over the Sextilius Pollio aqueduct. The two storied aqueduct had a total height of 16 m. It is also the oldest roman aqueduct in Turkey.

Degirmendere (Kenchrios) water conveyance system is 43 km long, conveying the water of Degirmendere Springs. It is probably dated from the first century AD.

The Kayapinar (Kaystros) water conveyance system is 40 km long. It conveyed the water of Kayapinar spring by means of a masonry conduit. It was probably built in second century AD. It was built between Kayapinar and northeast of Ephesus.

Figure–2: Sextilius Pollio aqueduct over Marnas Valley.

In addition to these water conveyance systems Ephesus' water needs were also supplied by local cisterns and wells. A dense terra-cotta pipe network, some of them still visible in situ, distributed water to the fountains, baths, and other buildings. Ephesus city had also an important sewerage network under the main street of the city discharging to the harbour.

Figure–3: The lead pipe with marble joints on display at Ephesus Museum.

Artemis Temple near Ephesus (one of the seven wonders of ancient world) was met its water needs by an inverted siphon. The inverted siphon was formed by lead pipes with marble joints. Inner diameter of the lead pipe is 8 cm, the wall thickness is 4.5 cm and the lenght of the lead pipe is 60 cm. The marble joints have 18 cm inside and 35 cm outer diameters. A sample of these pipes is on display at the Ephesus Museum. It is dated to 5th century BC. A similar marble joint resisted to 51 atmosphere internal pressure based on a laboratory test made in Australia (Ozis, 1994).

4.3. PERGAMON WATER SUPPLY SYSTEMS

The water supply of the Pergamon city was based originally on some fountains and cisterns of the city.

The first pipeline of Pergamon is probably dated to second half of the 3rd century BC leading water from eastern slope of Bergama (Selinus) River to the city. There were two water conveyance systems from Selinus river. One of them was a single terra-cotta pipeline with a water capacity of 3 l/s and the other system were consisted of two parallel terra-cotta pipelines with a total water capacity of 27 l/s and they had a lenght of more than 15 km. Both systems include inverted siphons with an internal pressure of 25-30 m.

Water conveyance system from Madradag to Pergamon consisted of three 45 km long parallel terra-cotta pipelines. After flowing through a double section settling basin water was conveyed to the Pergamon acropolis by means of an inverted siphon of single line lead pipes under a 190 m internal pressure (Ozis, 1996). Pergamon lead pipe inverted siphon had the highest pressure in the world of the hellenistic period (Fahlbusch, 1997).

Pergamon also had some other important water conveyance systems from the springs of Kaikos River and Geyiklidag. The completely ruined Ilyas River aqueduct belongs to Kaikos River conveyance system had 40 m height and 550 m lenght. It was one of the most noteworthy aqueducts in the world (Ozis, 1996).

4.4. ISTANBUL WATER SUPPLY SYSTEMS

The earliest known water supply line to Istanbul city was built in the time of Emperor Hadrian (117–138). It conveyed the water from west of the city to Sultanahmet Square. This water supply line was extended during the reign of Theodosius II (408–450). The second important water supply line was built durign the reign of the Emperor Constantine (324–337) and supplied water from the Istranca Mountains west of the city to the south of Edirnekapı. It was the longest of all water supply lines constructed by the Romans. The upstream point of this system is 6 km west of Vize and its total lenght was 242 km (Cecen,1996). Istanbul's third major water supply line was constructed in the time of Emperor Valens in 373. The water line, which was renovated and enlarged during the reigns of Justinian (527–565) and Constantine V (720–740), supplied the Achilleus Baths and Yerebatan (Basilica) Cistern. The fourth water line belongs to romans carried water from the Belgrad forest to the nortwest part of the city was probably built by Theodosius I (379–395). Epreror Justinian had large cistern constructed in the 6th century also repaired the Hadrian waterline.

When wells, cisterns and water resources of the city became inadequate because of population grew, the existing water supply lines and distribution networks inside the city were expanded and new sources added to existing systems. In the periods of Constantine V (741-775), Romanus III (1028-1034), and Manuel I (1143-1180) only repaired the existing systems. From tenth century deterioration of the old Roman water system as a result of sieges and eartquakes, prompted the Byzantines to make extensive use of cisterns. Small conduits were added to existing systems for water distribution from reservoirs and cisterns. They built new cisterns instead of supplying water from distant sources.

After the Latin occupation the water system of Istanbul became unusable. As soon as the conquest of Istanbul by the Turks in 1453, the restoration and reconstraction works of water systems had begun (Cecen, 1996). Roman period aqueducts dated from the 4th century, the Bozdogan (Valens), Mazulkemer, Karakemer, and Turuncluk, are still in good condition.

4.5. OTHER IMPORTANT WATER WORKS DATED FROM HELLENISTIC AND ROMAN PERIODS

Aspendos triple inverted siphon, two parallel stone pipe inverted siphons of Laodecia, stone pipe inverted siphon of Izmir under a 155 m internal pressure, Cevlik Dam near Antakya, Cavdarhisar Dam near Kutahya, Orukaya Dam near Corum, Boget Dam near Nigde, Ildir Dam near Cesme, three Dara Dams near Mardin, Lostugun Dam near Malatya, Sihke, Sultan and Faruk Dams near Van, Perge water conveyance and sewerage systems, Priene water conveyance and sewerage systems, and Cevlik diversion tunnel systems are some other important water works dated from Hellenistic and Roman periods.

5. WATER WORKS DATED FROM SELDJUKIDE PERIOD

The Seljukides constructed numerous passive water structures, like bridges throughout Anatolia. Malabadi Bridge with a 39 m single span width is the largest masonry bridge in the world. The flexible wooden foundation systems and sharp edge shaped piers of Seldjukide bridges exhibit high engineering skills. They built water mills and irrigation systems, fountains during their 10th-13th century period in Anatolia. They also have constructed several dams in Turkey, Iran and Turkmenistan (Ozis,1999).

Figure–4: Malabadi Bridge with a 39 m single span width.

6. WATER WORKS DATED FROM OTTOMAN PERIODS

6.1. ISTANBUL WATER SUPPLY SYSTEMS

After the caption of Istanbul in 1453 Ottoman Sultans gave special attentions to the water works of Istanbul. Halkali, Kırkcesme, Uskudar, Taksim water ways are some of the important water conveyance systems of Istanbul.

Halkali Water Conveyance System consisted of 16 different water conveyance lines with a total lenght of 130 km. This system had been constructed between 1453 and 1755. The names and construction dates of these conveyance lines are Fatih (1453-1481), Turunclu (1453-1481), Mahmutpasa (1453-1473) and Laleli (1454-1474), Bayazit (1481-1512), Kocamustafapasa (1511-12), Suleymaniye (before 1557), Mihirmah (before 1565), Ebussuut (before 1545-1574), Cerrahpasa (1598-1599), Sultan Ahmet (1603-1617), Saray Fountains (1623-1640), Koprulu (1656-1661), Miri (Beylik) (1730-1754), Hekimoglu Alipasa (1732-1750), Kasimaga, Nuriosmaniye (1748-1755) (Ozis,1996).

Kırkcesme Water Supply System was built by Architecht Sinan between 1554 and 1560. It includes many aqueducts, settling basins, water intake systems, sand traps, water measuring structures, city networks, fountains etc. Some parts of the system had a restoration because of a huge flood. The whole system had been completed in 1563 after the restoration. This system is still in use without any failure after more than 400 years. It fed the Rumeli side of Istanbul and was derived from the sources located north of the city. It has a total lenght of 55 km. It has four significant aqueducts. These are; Uzun Aqueduct (26 m height and 710 m length), Egri Aqueduct (35 m height and 342 m length), Maglova (35 m height and 258 m length), and Guzelce Aqueduct (32 m height and 165 m length). Topuz, Buyuk, Kirazlı and Ayvat Dams were added to system between 1620 and 1818 in order to ensure the seasonal flows regulation. Kırkcesme Water Supply System is a monumental water work totaly belongs to Architect Sinan.

Figure–5: Maglova (Muglava) aqueduct with 35 m height and 258 m length was constructed by Architect Sinan on the Kırkcesme water conveyance system (Cecen, 1996).

Figure–6: Guzelce (Gozluce) aqueduct with 32 m height and 165 m length was constructed by Architect Sinan on the Kırkcesme water conveyance system (Cecen, 1996).

Uskudar Water Supply System was constructed between late 16th century and 19th century. It contains numerous water balance towers. Water balance towers used on water supply systems of the cities like Pompei in Roman period but they extensively used by Ottomans. The aims of the water towers were changing the direction of flow, branching the flows, discharging the trapped air in the pipelines, controlling the defective sections, opening the pipeline to the atmosphere, and limiting the internal pressure of the pipelines.

Taksim Water Supply System was constructed in 1731 by Sultan Mahmut I. It has a total lenght of 23 km. Buyukdere aqueduct, Derbent inverted siphon, Topuzlu, Valide and Yeni Dams are the important features of the system. Hamidiye water conveyance system was constructed primarily for drinking water in the 19th century.

6.2. EDIRNE-TASLIMUSELLIM WATER SUPPLY SYSTEMS

Taslimusellim Waterways was also constructed by Architect Sinan. It has two branches called Sinankoy and Taslimusellim. Total lenght of the system is 50 km, total discharge capacity is 35 l/s and the system is still partly in service.

6.3. OTHER IMPORTANT WATER WORKS DATED FROM OTTOMAN PERIOD

Ottomans were also built several water structures like dams, flood protection canals, water mills, irrigation canals, aqueducts, water balance towers, and fountains in Turkey.

7. CONCLUSION

Turkey has been the crossroads of many civilization throughout the human being's history. During the last 4000 years, many civilizations left remarkable remains of water supply systems including pipelines (stone, terra-cotta, lead), irrigation canals, tunnels, galleries, inverted siphons, aqueducts, reservoirs, cisterns, flood protection canals, water mills, water balance towers and dams in the country. Present paper evaluated the various historical water works belong to Hittite, Urartu, Hellenistic, Roman, Byzantine, Seldjukide and Otoman periods in Turkey from hydraulic engineering point of view. The ancient hydraulic structures in Turkey convey a fine sense of hydraulic engineering knowledge even for today's hydraulic engineer's thought. The historical water structures in Turkey clearly prove that the predecessors of modern engineers knew the main rules of both open channel flow and pressurized flow.

Moreover based on a four thousand year hydraulic engineering tradition, Turkey is still constructing large-scale irrigation projects, dams and hydroelectric power plants.

Finally, it is hopefully anticipated that international and national interests both in the ancient water works of Turkey from the Hittite, Urartu, Hellenistic, Roman, Byzantine, Seldjukide, Ottoman periods and modern water works from Republic of Turkey period will continue to increase.

BIBLIOGRAPHY

1. Belli, O. 1997. Urartian irrigation canals in Eastern Anatolia. Istanbul: Archeology and Art Press.
2. Cecen, K. 1994. The longest Roman water supply line. Istanbul: Turkiye Sinai Kalkinma Bankasi.
3. Cecen, K. 1996. Sinan's water supply system in Istanbul. Istanbul: Istanbul Water and Sewerage Administration General Directorate.
4. Fahlbusch, H. 2000. *Water in human life: Technical innovations in hydraulic engineering in the last 5000 years*. ICID Journal. 49(4):1–16.
5. http://www.kultur.gov.tr
6. Garbrecht, G. 1987. *Hydrologic and hydraulic concepts in antiquity* in: Hydraulics and Hydraulic Research: a Historical Review. Balkema Publ. Rotterdam: 1-22
7. Hodge, A.T. 1992. Roman aqueducts & water supply. London: Gerald Duckworth & Co. Ltd.
8. Ozis, U. 1994. Su muhendisligi tarihi acisindan Turkiye'deki eski su yapilari. Ankara: Devlet Su Isleri Genel Mudurlugu.
9. Ozis, U. 1996. *Historical water schemes in Turkey* in: Water Resources Development. 12(3):347–383.
10. Ozis, U. 1999. Historical dams in Turkey. Ankara: Turkish National Committee of International Commission on Large Dams.