

Testing Flood Estimation Methods On Ancient Closed Conduits

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ABSTRACT

Beside a large number of ancient tunnels in long-distance water conveyance systems to ancient cities in Türkiye, five peculiar closed conduits, through which almost the entire discharge of watercourses were flowing, are investigated. These are the Çevlik (Seleucia Pieria) tunnel in Hatay province; vaulted structures covering the river bed in Bergama (Pergamon), in Sultanhisar (Nysa), in Acarlar near Ephesus (all four are leading examples of largest closed conduits from Roman times in the world); and the Bezirgan tunnel east of Kalkan, being an interesting example of emissary conduits draining the floods of closed basins. The hydraulic capacities of these conduits are determined; their corresponding flood return periods are estimated by four synthetic flood hydrograph methods. However, it was not possible to deduce any generalized conclusion based on the comparison of these results.

Keywords: tunnel, flood, drainage, Seleucia Pieria, Pergamon, Nysa, Ephesus, Bezirgan.

1. INTRODUCTION

Tunnels were often used in ancient long-distance water conveyance systems supplying ancient cities in Türkiye [Öziş, Baykan a.o. 2009] as well as abroad [Grewe 1998]. Closed conduits, as tunnel or vaulted structure covering the river bed, through which almost the entire discharge of watercourses were flowing, are seldom encountered. In fact, some of the largest ones are in Türkiye. Furthermore, ancient emissary conduits draining the floods of closed basins, are especially encountered in Mediterranean countries, where karstified soluble carbonate rock formations are dominant, like the southern regions of Türkiye.

Five closed conduits, through which almost the entire discharge of watercourses were flowing, are investigated. All are leading examples of largest closed conduits from Roman times in the world. Their hydraulic capacities are determined; their corresponding flood return periods are estimated by four synthetic flood hydrograph methods. Respective hydraulic capacities were compared to corresponding flood return periods in order to test the flood estimation methods and obtain eventual generalized results.

The locations of the five conduits are shown in Fig.1; their characteristics are dealt with in the next section.



Fig. 1 Locations of the Studied Hydraulic Structures

2. INVESTIGATED CLOSED CONDUITS AND THEIR HYDRAULIC CAPACITIES

2.1. Vaulted twin structure in Bergama (Pergamon)

The vaulted twin structures covering the Bergama creek in Bergama (Pergamon) [Öziş, Harmancıoğlu a.o. 1979, 2010; Grewe, Öziş a.o. 1994; Öziş, Baykan a.o. 2009] was constructed around 130 A.D. They are located under the floor of the Serapis temple in Pergamon; their length is 196 m and 183 m respectively, the slope 0,6 %. They have each a simple horse-shoe shaped cross section of 7,5 m height and 9 m width.

With a Manning's friction coefficient of $n=0,020$, the capacity of each structure is calculated as $360 \text{ m}^3/\text{s}$, thus the total capacity as $720 \text{ m}^3/\text{s}$. The entrance of the structure is shown in Fig. 2.



Fig. 2 Twin Creek Covering Structure in Pergamon-Bergama/İzmir (Photo: Ü.Öziş)

2.2. Vaulted structure in Sultanhisar (Nysa)

The vaulted structure covering the Tekkecik creek in Sultanhisar (Nysa) [Öziş, Harmancıoğlu a.o. 1979, 2010; Grewe, Öziş a.o. 1994; Öziş, Baykan a.o. 2009] has a broken alignment under the cavea of the stadion. The simple horse-shoe cross-section at the 25 m long upstream part has 7,0 m width, 5,7 m height. The 75 m long downstream part, after change of the direction, has 5,7 m width, 5,9 m height. The slope is 3,3 %.

With a Manning's friction coefficient of $n=0,025$, the capacity of the structure is calculated as $290 \text{ m}^3/\text{s}$. The interior and outlet of the structure is shown in Fig. 3.



Fig. 3 Creek Covering Structure in Nysa-Sultanhisar/Aydın (Photo: Ü.Öziş)

2.3. Vaulted structure in Acarlar near Ephesus in Selçuk

Long-distance water conveyance systems supplying Ephesus encompass quite interesting tunnel systems [Atalay, Öziş a.o. 2003; Öziş, Atalay a.o. 2005a, b]. Moreover, there is also a vaulted structure near Ephesus, with smaller dimensions than the ones in Pergamon and Nysa.

The vaulted structure covering the Karakaya creek in Acarlar near Ephesus [Öziş, Harmancıoğlu a.o. 2010] has a broken alignment. The simple horse-shoe cross-section has 7,0 m width, $2,1+1,2= 5,7$ m height. The upstream part is 6.4 m long, the downstream part 18,6 m, so that the total length is 25 m. The slope is 3,8 %.

With a Manning's friction coefficient of $n=0,035$, the capacity of the structure is calculated as $68 \text{ m}^3/\text{s}$. The entrance of the structure is shown in Fig.4.

2.4. Çevlik (Seleucia Pieria) tunnel system near Antakya (Antiochia)

The Çevlik (Seleucia Pieria) tunnels near Antakya (Antiochia) in Hatay province [Alkan & Öziş 1991; Garbrecht 1991; Öziş, Baykan a.o. 2009; Grewe, Öziş a.o. 2010] form the key element of a flood diversion system. The construction began in 1st century A.D. under the reign of Vespasianus, continued during the reign of Titus, and completed in 2nd century A.D. under the reign of Antonius Pius.

The system consists of a 15 m high diversion dam; a 55 m long approach canal; a first tunnel of 90 m length, with a simple horse-shoe cross-section of 6,3 m width and 5,8 m height at

the entrance, and an almost rectangular section at the exit; an intermediate channel segment of 64 m length in karst formations; a second tunnel of 31 m length, with a trapezoidal cross-section of 5,5 m width and 7,0 m height; and a 635 m long outlet canal. The total length of the system amounts thus to 875 m.

With a Manning's friction coefficient of $n=0,030$ and based on the determination of the water surface levels through step-by-step integration, the capacity of the system is calculated as $70 \text{ m}^3/\text{s}$, that of the tunnels to $150 \text{ m}^3/\text{s}$. The entrance of the structure is shown in Fig. 5.



Fig. 4 Creek Covering Structure in Acarlar (Photo: A. Alkan)



Fig. 5 Çevlik 1st Tunnel in Seleucia Pieria-Samandağ/Hatay (Photo: Ü.Öziş)

2.5. Bezirgan tunnel near Kalkan

The Bezirgan tunnel, east of Kalkan in the mediterranean region [Genç, Baykan a.o. 2010; Öziş, Harmancıoğlu a.o. 2010] is an interesting example of emissary conduits draining the floods of closed basins in karstic areas.

The tunnel drains the flood waters of the polje, where the antiqua city Pirha was located. The width of the conduit is 1,08 m, the lower part has a rectangular cross-section of 1,55 m height, the upper part a pointed triangular section of 0,67 m height; thus the total height is 2,22 m. The length of the tunnel is 250 m, the slope is 1,6 %.

With a Manning's friction coefficient of $n=0,030$, the capacity of the tunnel is calculated as $5 \text{ m}^3/\text{s}$ for free flow, $8 \text{ m}^3/\text{s}$ for flow under a pressure of 6 m over the invert. Various views of the tunnel are given in Fig. 6.



View towards outside of the tunnel (Photo: Baykan)



View towards inside of the tunnel (Photo: Baykan)



Drainage canals (Photo: Büyükyıldırım)



Plan of the basin with tunnel (at the bottom)

Fig. 6 Bezirgan Drainage Tunnel in Pirha-Kalkan/KaşAntalya

3. FLOOD ESTIMATION METHODS

There were no representative gaging stations set up in all cases, so that synthetic unit hydrograph methods (based on topographical, vegetative, meteorological data) have to be used for estimating flood flows. Four such methods were used in the estimations.

The Snyder [Chow 1964] and Mockus [Ogrosky and Mockus 1964; Bureau of Reclamation 1965] methods were developed in the U.S. and also widely used abroad. The DSI

Synthetic method [Mat 1964; Özdemir 1969] was developed for Türkiye in general; the Günerman method [Günerman 1976] for the Egean region of Türkiye.

Flood frequencies are evaluated through the use of Gumbel's double exponential log-extreme distribution [Yevjevich 1972; Kite 1977], although not linearized in certain cases.

4. RESULTS AND CONCLUSION

The frequency distributions of flood peak flows at the entrance of the investigated closed conduits are given in Fig. 7.

The Snyder method displayed a tendency to under-estimate the floods; the Günerman method appears to give more conservative results; Mockus and DSI Synthetic methods yielded close to the average results.

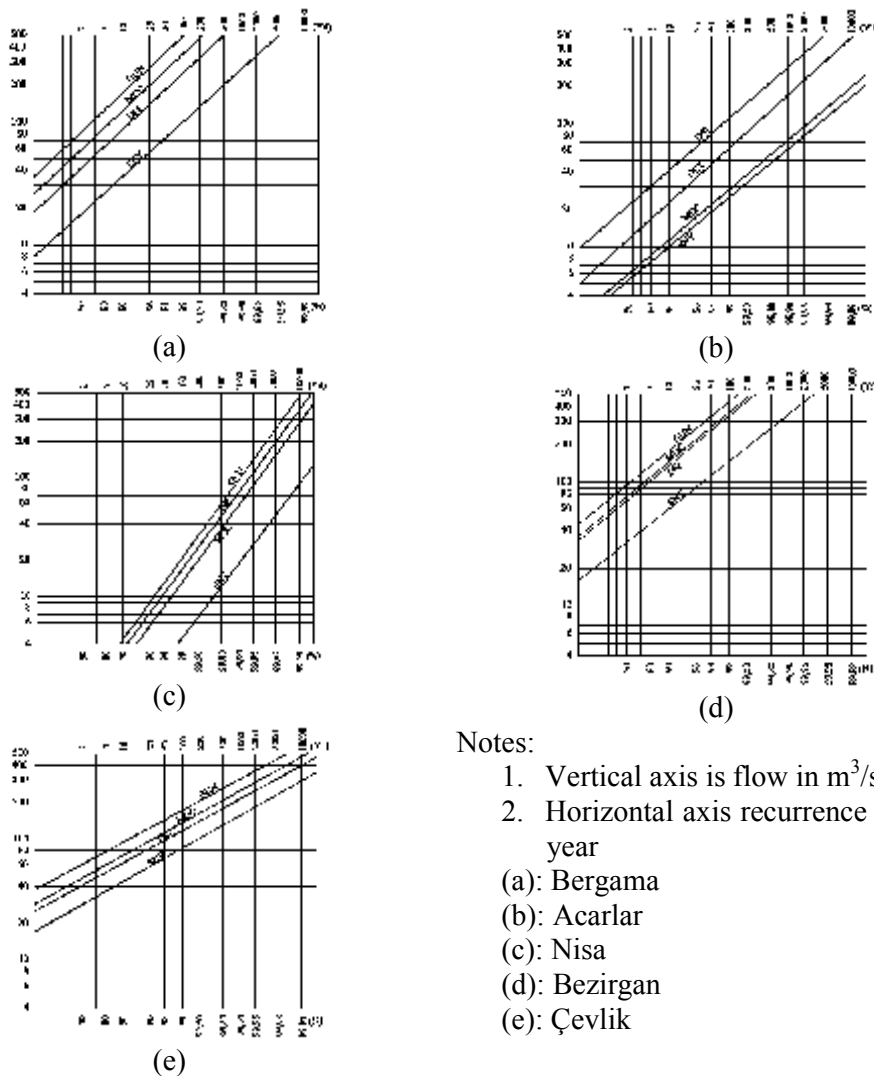


Fig. 7 Frequency Distributions of Synthetic Flows for Studied Structures

The hydraulic capacity of the conduit corresponds to a mean flood recurrence interval in the order of 700 years for Pergamon, 13.500 years for Nysa, 170 years for Acarlar, 9 years for Çevlik, and almost every year for Bezirgan.

Hence, it was not possible to deduce any generalized conclusion based on the comparison of these results.

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