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Hydraulic analysis of the water supply system of the Roman city of Perge

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ABSTRACT

Fluid dynamics is a valuable tool to characterize and to interpret ancient hydraulic remains. In this study, the peculiar water channel situated in the middle of the main street of the ancient Roman city of Perge is investigated. More precisely, the water flow in the channel (and in diversions originating from this channel) is characterized and the results are analyzed in order to gain a better understanding of the city water distribution system. The peculiarity of the system lies in the unusual channel dimensions in Roman standard, as well as in the presence of blocks perpendicular to the flow, regularly placed every 7 m on the whole channel length. Furthermore, upstream of some of the blocks, terracotta pipes are inserted in the walls of the channel. They were bringing water to the east and to the west of the city. The results show that the channel must have been the only north-south water transportation axis of the city and that the presence of the blocks was imperative, not only to ensure the aesthetic of the channel, but also its functionality.

1. Introduction

The work presented in this paper is dedicated to the analysis of an ancient hydraulic system in the Roman city of Perge (or Perga). Many archaeological remains of hydraulic installations attest for the remarkable technical capability of the Roman engineers in water supply. They were able to build aqueducts with a regular slope on distances up to 150 km, such as those bringing water to the Middle-East cities of Apamea (Haut and Viviers, 2007), Aspendos (Kessener and Piras, 1998) or Ephesus (Ortloff and Crouch, 2001; Öziş et al., 2014). Aqueduct bridges and inverted siphons, allowing for water transportation throughout valleys, are other monumental installations (Kessener, 2000; Ortloff and Kassinos, 2003).

In contrast with the numerous archaeological remains of Roman hydraulic installations, there are relatively few written documents attesting to the mastery of the Roman engineers, with two notable exceptions: the works of Vitruvius and of Frontinus. Vitruvius, in his *Ten Books on Architecture*, dating from the late 1st century BCE, dedicates a whole chapter to aqueducts, wells and cisterns (Morgan, 1914). Frontinus, Rome water commissioner at the end of the 1st century AD, means to show in his *The Aqueducts of Rome* 'how great is the < water > supply which satisfies not only the necessary uses and reserves (both public and private) but those which give pleasure as well (…)' (Rodgers, 2003), underlying the importance of water as a foundation of the Roman culture (Rollier, 2010).

The works of Vitruvius and Frontinus detail the building techniques used to conceive the Roman hydraulic installations. Their works reflect that the Roman engineers used the skills and knowledge developed by the school of Alexandria (Viollet, 2004). These engineers were instructed with the findings of Euclid, the father of geometry, and of Archimedes, the greatest mathematician of the Antiquity, father of the hydrostatics. The Greek mechanics contained a lot of information regarding static phenomena, but was including practically no notion of dynamics. Hero of Alexandria was the first to formulate the notion of flow rate, but too late to be taken into account in the works of Vitruvius and Frontinus (Viollet, 2004). Therefore, while these works give a lot of construction details about the Roman hydraulic installations, they do not provide quantitative characteristics of the flow that was taking place in these systems (flow rate, velocity, water level, pressure drop…).

Modern fluid dynamics, whose development started in the 17th and 18th centuries, and, more recently, computational fluid dynamics opened new perspectives in fluid flow studies (Patankar, 1980). With the current knowledge in fluid dynamics and the computational power available today, it is possible to calculate the water flow that was taking place in well preserved hydraulic remains. Therefore, in the last 40 years, there has been the emergence of a new type of studies resulting from the collaboration between archaeologists and engineers, aiming at characterizing and interpreting ancient hydraulic remains through the modern knowledge in fluid dynamics (Chanson, 2002; Farrington and Park, 1978; Gale and Hunt, 1986; Haut and Viviers, 2007; Ortloff and Crouch, 1998; Ortloff and Kassinos, 2003; Tseropoulos et al., 2013; Vannesse et al., 2014). In other words, these studies supplement field observations of ancient hydraulic installations

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Fig. 1. Left side: Position of the Roman city of Perge on the current map of Turkey. Right side: Schematic map of Perge (Haut and Viviers, 2012).

with information about the flow that was taking place in these systems, obtained by solving fluid dynamics equations. The present work, in line with these previous studies, proceeds from the discovery of a peculiar water channel in the Roman city of Perge.

The archaeological site of Perge is located 11 km from the Mediterranean coast in Turkey, near Antalya (see Fig. 1). Archaeological evidences set the formation of the city during the 12th century BCE, when Archaean colonists came to the region after the Trojan War (Bakacak, 2007). Following the arrival of Alexander the Great in 334 BCE, the site passed under the control of various Hellenistic kingdoms. Later on, during the Roman Empire, Perge gained a genuine prosperity, especially in the 2nd and 3rd centuries AD (Schram et al., 2015). The structure of the Roman Perge, still visible today, is typical of Roman cities of that time. The city was organized around two main orthogonal colonnaded streets: the Cardo Maximus, the main street oriented north-south, from the Acropolis to the Agora, and the Decumanus, oriented east-west (González-García and Magli, 2015). A schematic map of the city remains and a view of the archaeological site from the Acropolis are presented in Figs. 1 and 2. Most of what is visible at the site dates from the 2nd and 3rd centuries AD (Turkish Archaeological News, 2015).

As it can be seen in Fig. 1, Perge Cardo Maximus starts from the so-called Northern Nymphaeum, a double storey fountain-portal complex, and makes two minor turns, due to pre-existing buildings dating from the Hellenistic period (Bakacak, 2007). In the middle of the Cardo Maximus, a masonry channel is observed; supposedly build to convey water from the north to the south of the city. A picture of this channel is presented in Fig. 3. Such a channel in the middle of the main street is a unique feature in Roman architecture (Bakacak, 2007). Moreover, according to Roman standards, this channel has peculiar dimensions. Indeed, its width is approximately three times its height while, typically, the channels of Roman aqueducts have a height approximately twice their width (Viollet, 2004). Water was fed to this channel by the Northern Nymphaeum (see Fig. 4), which itself was supplied by water carried in a channel running along the Acropolis. The water channel in the middle of the Cardo Maximus is also the source of diversions (terracotta pipes) that were bringing water to the rest of the city. Finally, blocks of identical size were regularly placed inside the channel, all along its course (see Fig. 3). Several of these blocks can still be observed today. This is another peculiarity of this remarkable hydraulic system.

This peculiar water system and, more generally, the Roman city of Perge are only mentioned scarcely in the literature. Therefore, the objective of the work presented in this paper is to characterize the water flow in the channel in the middle of Perge Cardo Maximus (and in the diversions originating from this channel) and to analyze the results in order to gain a better understanding of the city water distribution

Fig. 2. View, from the Acropolis, of the archaeological site of the city of Perge (Blaze, 2011).