GEOTECHNICAL ENGINEERING PRACTICE IN THE MYCENAEAN CIVILIZATION (1600-1100 BC)

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Στην εργασία αυτή γίνεται μια παρουσίαση των Μυκηναϊκών έργων πολιτικού μηχανικού με έμφαση στη γεωτεχνική μηχανική. Αρχαιολογικά ευρήματα και αρχαία κείμενα χρησιμοποιούνται σε αυτή τη διερεύνηση. Από τη διερεύνηση αυτή καθίσταται προφανές ότι οι Μυκηναίοι μηχανικοί ήταν ικανοί κατασκευαστές με εκτεταμένη εμπειρία σε γεωτεχνικές κατασκευές που περιλαμβάνουν τείχη, δρόμους, γέφυρες, αναχώματα καθώς και υπόγειες κατασκευές και σήραγγες. Η μέθοδος κατασκευής αυτών των έργων είναι σε μεγάλο βαθμό άγνωστη, αλλά η λεπτομερής μελέτη των αρχαιολογικών ευρημάτων μπορεί να αποδώσει χρήσιμες πληροφορίες για τις κατασκευαστικές συνήθειες αυτού του πολιτισμού.

This paper provides an overview of the Mycenaean civil engineering projects with emphasis in geotechnical engineering. Archaeological findings and literature resources are used in this study. While there are difficulties in this approach, it becomes evident that the Mycenaean engineers were competent builders with extensive experience in geotechnical construction that included fortifications, roads, bridges, embankments as well as underground construction and tunnels. The method of construction for most of these projects is largely unknown but detailed study of the remains could yield useful information on the construction practices of this civilization.

Introduction

The majority of texts on the history of science and engineering (de Camp, 1966, Hodges, 1992) tend to ignore the engineering achievements of the Mycenaean civilization. Typically, the achievements of the Egyptian and Mesopotamian civilizations are presented and the discussion continues to classical Greece and the Roman Empire. However, the Mycenaeans, whose civilization flourished from about 1600 BC to 1100 BC in Greece, are responsible for many engineering achievements most of which still have not been studied adequately.

This paper provides an overview of the remains of some of the Mycenaean projects and the engineering construction practices that today are part of the civil engineering profession and specifically of the geotechnical engineering field.

Sources of information

Any attempt to understand the geotechnical practice of this largely unknown civilization is based on two main sources of information: i) Archaeological findings/remains, ii) Literature resources

In studying the archaeological remains it is first necessary to recognize that any information collected on the construction practices of these monuments represent only a portion of the practices of that civilization. This is due to a number of reasons:

- The proven use of a construction method in a project does not imply that other methods were not available or were not used at that time.
- The preserved remains likely represent practices of monumental construction (Jansen, 2002), i.e. large-scale projects of high construction quality.
- Structures of monumental construction could have been destroyed in the course of time due to natural or human-induced causes.
- High quality practices using non-durable materials (e.g. wood) simply disappeared with time.

In addition to the above, evaluating the construction method of projects that were preserved is not a simple task because the solution to the problem is not unique: Different construction techniques can result in the same final product.

Literature resources are an important source of information. However, limited information is available on the Mycenaean geotechnical practice. Written resources of the Mycenaean period - in the form of plates found in Pylos and Crete - are limited. Written texts related to the particular period are the Homeric poems, which were composed roughly about 300 years after the decline of the Mycenaean civilization. Interestingly, these poems provide a surprisingly large amount of information on geotechnical engineering (Zekkos et al. 2003). Historians, geographers, or poets occasionally provide additional information, however all of them lived much later. For that reason all the literature resources have the same problem: The possibility that the provided information is inaccurate. The above brief discussion is intended only to underline the inherent difficulties in attempting to collect information on the geotechnical practices of the Mycenaeans.

From the archaeological findings and the literature, the following project categories related to geotechnical engineering can be recognized: i) fortifications, ii) underground shafts (graves), iii) retaining walls, iv) roads/pavements, v) bridges, vi) hydraulic works, vii) dams/embankments, viii) tunnels, ix) harbors, x) quarries/mines, xi) residential construction. Due to page limitations only some of the above project categories will be discussed.

Fortifications

The size of the fortifications is maybe the most widely known characteristic of the Mycenaean construction. But it is not only the size of the fortifications of Mycenae, Tiryns, Gla, or Orchomenos, that is impressive, when the size of the building blocks used in the construction of the fortifications is considered. In Tiryns, stones are typically 2-3 meters long and more than a meter in thickness and height. The construction of these walls appeared to be such an amazing task that according to the Greek tradition King Proitos invited Cyclops to build the citadel walls (Pausanias on Korinthia)

The blocks of the walls are made by locally available material. Limestone rocks are used in Tiryns, mostly conglomerate in Mycenae. In Mycenae, three different building techniques can be observed in the fortifications: a) Cyclopean type masonry, generally consisting of slightly hewn blocks. The stone dimensions were larger on the two wall faces (interior and exterior) and smaller in the gap between them, which was filled with smaller stones and soil. The Cyclopean type masonry is the oldest one and it was also used in combination with the subsequent system of rectangular masonry. b) Rectangular masonry that consists of carefully hewn rectangular blocks laid on one another in regular courses. This type of masonry was first used probably in 1250 BC. The rectangular type was used to construct only the outer side of the wall while the interior side was constructed with Cyclopean-type masonry. c) Polygonal masonry which is generally composed of polygonal blocks fitted together like pieces of a puzzle. The care with which the blocks are fitted together and the attention to details suggest that the Mycenaean technicians were skillful in working with rock, transporting it, and placing the blocks in the "as-designed" position.

Underground shafts (bee-hive graves)

Excellent examples of the competence of the Mycenaeans in geotechnical construction are the "bee-hive" tombs. Those are large-vaulted tombs, also known as "treasuries". Lord Taylour (1983) reports that at his time more than 100 such tombs had been excavated in Greece and the existence of many more was suspected. The construction method of these tombs is similar to the Cut & Cover method of construction: The hill is excavated, the vault is constructed and then soil is placed on top of it. Figure 1 shows a cross-section of a typical "treasury". The final result blends nicely with the geomorphological features of the environment making those shafts difficult to identify despite their large size. One of the most widely known graves is the "treasury of Atreus". Figure 2 illustrates the front view of the treasury. The chamber has a diameter of 14.6 m and a height of 13.5 m. The interior side of the conglomerate stones is carved creating a vault (θόλος). A passage with vertical slopes, lined with large conglomerate stones of rectangular masonry leads to the entrance of the chamber. The entrance of the chamber is supported by a large lintel, which is 9 m long, 5 m wide and 1.2 m in height, weighing about 120 tons. Dr. Schuchardt who was helping Dr. Schiemann's excavations in Mycenae mentions that "great mechanical ability in quarrying and conveying stone must have been necessary to hew out such a block, bring it to the spot and then to work it so accurately and lay it so carefully" (Schuchhardt, 1879).

The method of construction of these chambers did evolve. The treasury of Atreus is probably an "evolved" version of this type of construction dated around 1250 BC. Older versions of these graves do not include the protective rectangular, masonry lining of the passage. Failures probably convinced the engineers to line the slopes. Another interesting feature of this construction that is not observed in all the tombs is the waterproofing of the tomb. A clay liner is placed around the vault to avoid water seepage inside the chamber. In the "tomb of Aigisthos" there are three clay layers alternated with local earth to achieve waterproofing. It is clear that the Mycenaeans were monitoring the performance of the tombs and were modifying the construction to improve their performance.

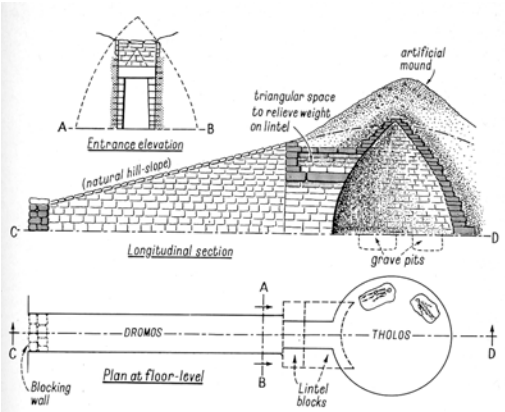

Fig. 1: Typical cross-section of a treasury (Taylour 1983)

Fig 2: View of the Atreus treasury

Retaining Walls

Retaining walls were extensively constructed as part of road construction projects, in other facilities, and as already discussed, in vaulted graves. All retaining structures are gravity-type, i.e. the stability of the supported embankment is ensured by the large weight of the blocks that form the wall. Many examples of this type of construction exist. Figure 3 shows a large embankment supported by a vertical gravity wall consisting of large, roughly hewn blocks. Retaining walls were commonly constructed in road projects as discussed in the following section.

Roads & Pavements

The Mycenaeans had a complicated transportation system that consisted of a primary network of roads and many secondary roads. In the vicinity of Mycenae, an extensive network of roads intended to serve the local needs is still preserved and has been studied by several researchers (Steffen, 1884, Jansen 2002, Iakovidis and French, 2003). Jansen (2002) explains why this network of roads was preserved in Mycenae. Indications of local road networks have been found in other regions too. An inter-regional system of roads that were connecting the main cities is also suspected but archaeological findings are rather ambiguous. One of the reasons of the ambiguity is that these roads were probably continuously used in the following centuries (Classic, Roman, Middle Ages) destroying any proofs of their origin. Homer in various occasions refers to this extensive network of roads by using the expression "when the night falls, all the roads darkened" (Odyssey, Γ/94, O/182-185, O/295-296). Also in Odyssey, Telemachos travels from Pylos to Sparta using a wheeled chariot. An engineered road that allowed wheeled traffic is required for that to happen.

Jansen (2002) uses the word "highways" to describe a built or engineered, surfaced and maintained line of communication that was at least 2.5 m wide. He identifies four main highways near Mycenae. These highways were used by wheeled traffic and are generally following the terrain contours avoiding steep grades. Along the highways, retaining walls are used at the side to protect the road or below the road to support the highway. Bridges are constructed to cross rivers. Culverts are used to allow the water to flow from the upper slopes of the hill downgrade without flooding the road.

A cross-section of a highway is shown in Figure 4. Stone terrace walls and a layer of varying thickness consisting of large unworked stones and earth are used depending on the geomorphology of the area. On top, is placed a layer of small stones and earth having a thickness of about 25 cm. The road surface was probably paved by a mixture of earth sand and small gravel. Jansen (2002) in his overview of the construction of the Mycenaean highways notes that "the new element is not the works themselves but the scale. It requires a centralized authority to be able to collect and maintain the workforce for such building projects".

Fig. 3: View of a gravity-type retaining wall in the Mycenaean palace.

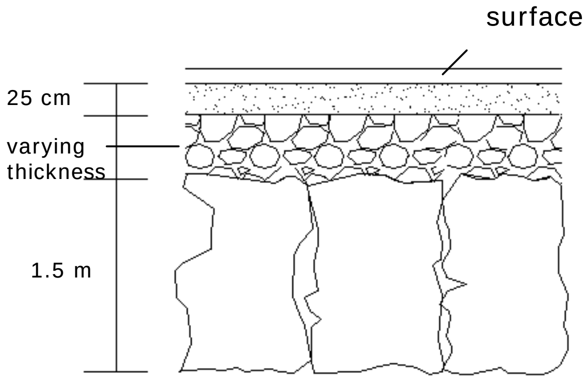

Fig. 4: Highway cross-section.

Bridges

As part of the road network, a large number of bridges were constructed to cross streams and rivers. In the Argolida region, there are many remains of bridges while a number of them are still used by local traffic. The Mycenaean bridge construction consists of courses of large limestone blocks that form a corbelled arch, an inverted V triangle, through which the river flow is allowed. Examples of those bridges are Dragonera bridge (15 m long, 4 m wide, 1.5 m tall), Lykotroupi bridge (15 m long, 5 m wide, 2 m tall) as well as Kazarma bridge. When necessary, retaining walls were used to the sides of the bridge to protect the bank and the bridge from erosion. It is likely that wooden bridges were also constructed but no remains have been found.

Hydraulic works – Dams - Embankments

Extensive hydraulic works were constructed by the Mycenaeans to create land for agriculture. Recent studies on the myths of Hercules suggest that many of the hero's labors were related to hydraulic projects constructed by ancient engineers (Lazos, 1999).

The most impressive hydraulic works are those of the Minyans in Orchomenos, dated in about 1300 BC. The purpose of the projects was the drainage of lake Kopais and the use of land for agriculture. The projects included the construction of a main canal and levees that collected the water of the rivers, the de-sedimentation of the naturally occurring sinkholes (karsts) in the local limestone formation that leaded the water of the lake into the sea, the construction of a tunnel that had the same purpose as the karsts, the construction of canals that were used for agriculture in the plain and the construction of the fort of Gla. Iakovidis (2001) characterizes these works the most impressive multi-project of ancient European history.

The main canal had a length of 43 km and a total depth of 5m. It was protected by 2 m high and 30 m wide dykes. The inner sides of the dykes were faced with 2 to 2.5 m thick Cyclopean walls that protected the embankments from erosion. Iakovidis (2001) estimates that 2 million m^3 of earth and 250,000 m^3 of stones were used to build the dykes. The tunnel which together with the karsts guided the water from the canal to the sea, had a length of 2,500 m, a height of 1.8 m, and a width of 1.5 m. Sixteen vertical shafts were excavated along the axis of the tunnel and through those the tunnel was excavated (Knauss et al, 1984).

Another project of interest is the "Dam of Tiryns" studied by Balcer (1974). It is located 1 km to the east of Tiryns and is really an embankment intended to protect the city of Tiryns from the flood waters, and direct them on a channel excavated for that purpose, allowing also the irrigation of the land. The construction method of the dam has not been adequately studied. Observations of the embankment as it stands today suggest that there are many similarities with the embankment in Kopais as well as the roads, retaining walls and bridges found in Argolida. Cyclopean walls protect both sides of the embankment from erosion. Three courses of cyclopean masonry can be seen, reaching a height of about 2 m from the bed of the present channel. The material from the excavation of the channel was probably used for the construction of the dam.

The reinforcement of the embankments with cyclopean masonry is consistent with the information provided by Homer. In the Iliad (E/87-92) the poet compares the attacking fury of Diomidis with the floodwaters of a river that can destroy the embankments even though those are reinforced.

Tunnels

Tunnels are even today one of the most difficult construction projects. It would not come as a surprise, if the Mycenaeans did not construct any tunnels. However, there are at least two tunnels that belong to the Mycenaean period. The first one, near Orchomenos, has already been mentioned. The second is located within the walls of Mycenae. Lord Taylour (1983) calls it "a marvel of engineering". The entrance of the tunnel was within the walls but the tunnel leads to a depth of 18 m below the surface outside the walls above the spring called Persia which is 360 m to the east of the palace. The opening of the tunnel has again the typical corbelled arch construction, which is seen in the bridges (Figure 5). While we do not know exactly how the water was entering the tunnel, some terracotta pipes have been found at the roof of the cistern located at the end of the tunnel. The floor of the cistern is covered with waterproof cement to prevent seepage.

Fig. 5: Entrance and interior of the tunnel that leads to the cistern

Harbors

No Mycenaean harbors have been identified to our knowledge. However, we do know that the Mycenaeans dominated in the sea after the Minoans. Therefore, it should be expected that harbors existed to support the trade and military fleets. Homer mentions that it was common to pull the ships on the sandy beaches. Also, the poet in numerous occasions refers to harbors and the facilities of those harbors, such as different types of moorings, stone facilities for the repair of ships and water supply facilities (Odyssey, E/40, E/404-405 Z/262-271, H/43-45, K/87-90, K/125-127, M/5-6, M/305, N/195-196, O/471-474).

Concluding remarks

It is generally assumed that ramps were used for the construction of the Mycenaean infrastructure similarly to the pyramid construction. However, the geomorphology of the area, the construction time, the geographic distribution of these projects as well as other secondary observations suggest the use of a more efficient method of construction. The method of construction (constructability) of the Mycenaean infrastructure needs to be studied further.

The large number and types of projects that are still preserved, without accounting for projects that have not been preserved, suggest extensive experience in construction. These construction practices, and the accumulated knowledge that supported the construction of these projects have not been systematically studied yet. The paper made a brief overview of the projects based on the information provided by the archaeological findings and the literature resources. A detailed combined investigation of some of these projects by archaeologists and engineers could shed some light on the construction practices of the Mycenaeans.

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