SOIL INVESTIGATION ON THE BOTTOM OF OHRID LAKE BY CPT-U TEST

Done Nikolovski

International Balkan University, Civil Engineering, Skopje

Abstract. *In 2008, the activities for construction of museum complex started on wider scale at the archeological site on the peninsula Gradishte Ohrid Lake, by patronage of the Board for cultural heritage of the Republic of North Macedonia. The works are to create an authentic reconstruction of prehistoric palafitte settlement on timber piles, located in the place called "Bay of the bones", which dates from the late bronze age and beginning of iron age, in the period of 1500 – 700 BC. The aim of such activities was to build a museum on water that would be unique to the Balkans by its form, construction and cultural heritage. In the first phase, an offshore investigation with CPTu tests was conducted for the means of this construction, for definition of the geotechnical characteristics of the soil in the bottom of the lake, as well as defining of the depth on the base rock material. In accordance with the results from the geotechnical investigations, the timber piles construction is designed and executed, on the same place in the lake where prehistoric artifacts were found. In this paper the geotechnical investigations, technical characteristics and details of the authentic reconstruction of the timber pile construction are detailed.*

1 INTRODUCTION

The Ohrid Lake was formed by tectonic forces, 2-4 million years ago, therefore it is considered to be the oldest lake in Europe and one of the oldest in the world, along with the Baikal Lake in Kafkaesque and the African Lake Tanganyika. In Ohrid Lake more than 146 endemic species and fauna are found, mostly because of its age, and the fact that it is surrounded by hills and mountains. As a result, in 1980, UNESCO proclaimed it as site of cultural and natural values of the global patrimony. Still, this natural system does not only abound in endemic species and fauna, but also at the bottom of the lake exceptional archaeological values from the old prehistoric period, such as pile settlements, have been preserved.

Pile settlements, as a way of living for people in the past, were especially characteristic of the period of Prehistory, in the Neolithic, Eolithic, Bronze and Iron Age. They were built and used, generally, for the protection of the prehistoric man from the attacks by wild animals as well as by other tribes. This also allowed them to obtain food either by water or by land. These pile settlements, in Europe can be mostly found in Switzerland, Northern Italy, Germany, Austria etc., originating from various chronological periods. Pile settlements in Macedonia were first mentioned by the antique Greek historian Herodotus (B, 16) who described the Prasiade Lake, nowadays known as the Dojran Lake. Apart from the remains of prehistoric pile settlements found on the territory of the Dojran Lake after the archaeological research conducted in the last years of the 20th century, such remains have also been found on the territory of the Prespa Lake and Ohrid Lake in North Macedonia.

The only settlement of this kind which has been reconstructed, and which can be found on the coast of the Ohrid Lake, in the Bay of the Bones, will be the topic of this research.

2 GENERAL CHARACTERISTICS OF BAY OF BONES PILES SETTLEMENT

For the first time in Macedonia, in the years between 1997-2005 and 2007-2008, underwater archeological researches were carried out in the Ohrid Lake next to the Gradiste peninsula, more specifically in the Bay of the Bones. These detailed researches at the aforemetioned location, resulted in the discovery of a prehistoric pile dwelling settlement, where about 6000 remains of timber piles with a diameter of 13.0-30.0 cm, comprising a surface of 8500 m2, were registered. These piles, grouped in such a way, constituted the foundation of a joint wooden platform. According to the archaeological researches, it is assumed that 20 prehistoric residential facilities built from similar material had

been located above this platform. Regarding the authentic construction execution, it is important to mention that these piles were registered at a depth of 3.0-5.0 m, while the nearest piles are found 12.0 m from the coast of the lake, which is oriented South from the Gradiste peninsula. The survey of the bottom of the lake registered ancient ceramic pots, stone artifacts, animal bones and many other objects used as tools.

Figure 1. Remains of wooden objects at bottom of Ohrid Lake

Figure 2. Remains of timber piles at bottom of Ohrid Lake

Based on the results obtained from these detailed researches, and in accordance with the archaelogical analysis of the objects taken out from the bottom of the Ohrid Lake, it can be said with absolute certainty that this pile settlement dates back to the late Bronze Age and the beginning of the Iron Age, that is the period between 1500 and 700 B.C. Due to these reasons, this object has raised considerable interest among the members of this professional field. As a result it was decided to start the construction of a museum on water, the only one of this kind on Balkans, under the auspices of the Macedonian Ministry of Cultural Heritage.

3 GEOTECHNICAL INVESTIGATIONS

The specific location of the pile settlement's construction in the waters of the Ohrid Lake imposed the need of uncommon geotechnical investigations. It was decided to conduct offshore soil investigations through the CPTu test, keeping in mind the difficulties in handling the standard drilling equipment in a limited space, as well as the inability to obtain an undisturbed soil sample from the bottom of the lake. Undoubtedly, as a result of these reasons, the CPT test has been an essential part of offshore soil investigations in the last 40 years.

The position and dimensions of the platform, generally required the conduction of the tests at 6 investigation points, all in 20-40 m distance from the shore of the Ohrid Lake. Taking into consideration its distance from the shore of the lake, the conduction of the offshore tests was adapted to shallow waters (<30 m), by placing the equipment on a floating barge with a central core in the middle. The tests were provided using an electric piezocone CPTu, type ENVI Memocone.

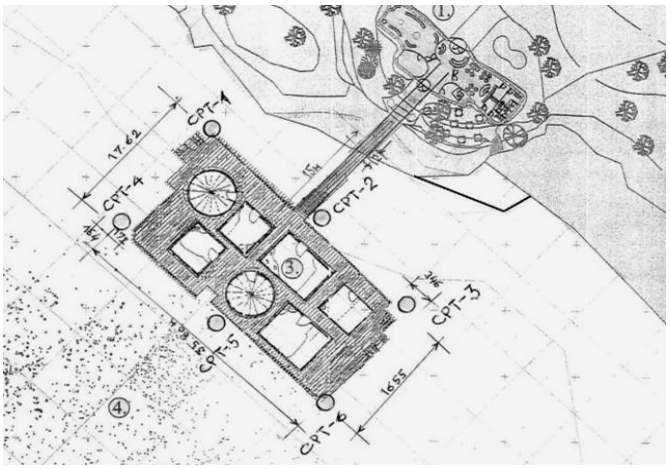

Figure 3. Layout with disposition of investigation points

Despite the fact that the tests were carried out in shallow waters, care was taken for the equipment to be well anchored to the bottom of the lake in order to prevent any horizontal displacements and inclination. In this way the free-standing casing protrudes trough an anchored barge, with the hydraulic jacking system mounted on a stable casing (Figure 4).

Figure 4. Offshore investigations with CPT-u

Because of the nature of the constructions itself, it was very important to determine the soil profile of the lake bottom, which is without doubt one of the biggest advantages of this type of in situ testing. The tests were carried out to varying depths, until the power of the penetrometer of 200 kN was reached which indicates the appearance of the base rock material, limestone. The base rock material is registered at a varying depth from the surface of the lake, and with an inclination of n ≅ 1:2.8, with E-W orientation i.e., from shore to the lake (Figure 5).

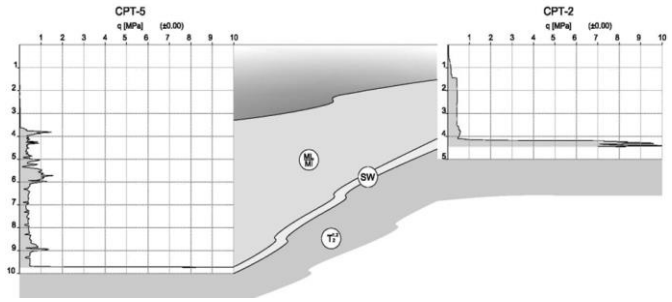

Figure 5. Offshore investigations with CPT-u

The identification of the soil materials will be done according to Robertson (1990) normalized charts, which offer a three-dimensional system for soil classification. The advantage of this popular method for classifying soil materials to others is that it uses all three series of data from the CPTu test (qt, fs, U2) which is essential for this kind of offshore investigations. The normalization of the CPTu data, will be done according to the equations (1) to (3) below (Wroth, 1988). Considering that the piezocone used in the tests, only measures the pore pressures behind the cone U2, the normalization of the sleeve friction fs to ft will not be done.

$$Q_t = \frac{q_t - \sigma_{vo}}{\sigma'_{vo}} \quad \text{normalized cone resistance} \quad (1)$$

$$F_r = \frac{f_s}{q_t - \sigma_{vo}} \quad \text{normalized friction resistance} \quad (2)$$

$$B_q = \frac{\Delta U}{q_t - \sigma_{vo}} \quad \text{pore pressure ratio} \quad (3)$$

Analyzing the obtained data values from all 6 conducted tests, it can be concluded that the registered data values, according to all three parameters, indicate materials of a similar kind in a quasi - homogenous zone up until the registering of the base rock material. As a result, the series of values of a characteristic CPTu test will be shown and analyzed below (Figure 6).

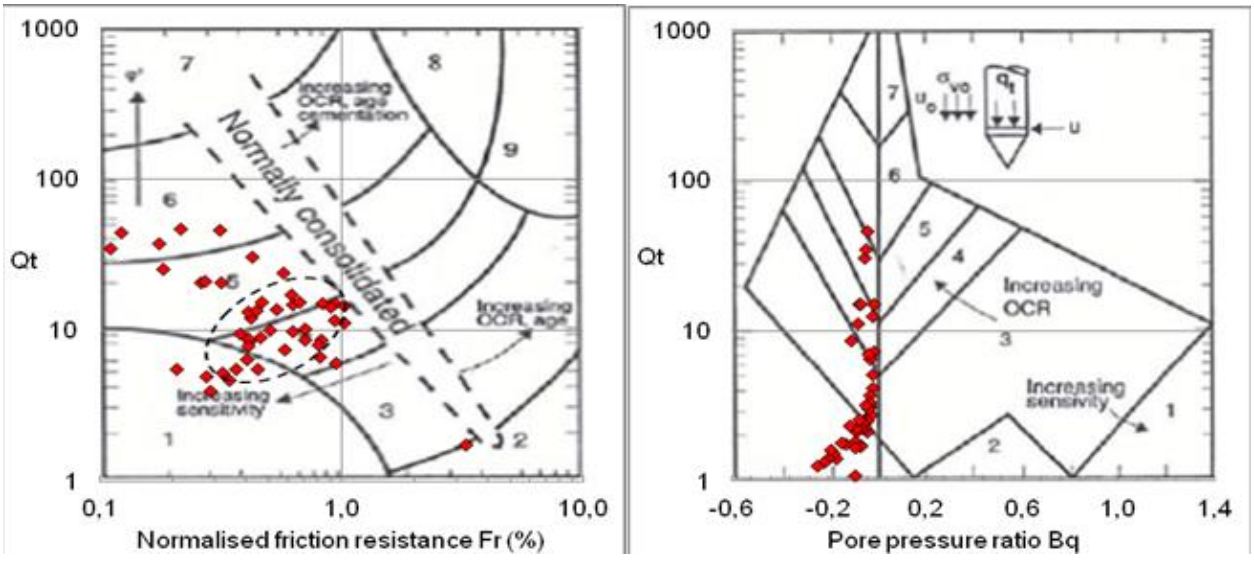

Figure 6. Charts of soils classification from CPTu test, by Robertson (1998)

According the diagrams, the series of values are generally concentrated around zones 1, 3 and 4, interpreted as sensitive fine-grained soils and silty-clay mixtures, which overlaps with the other examinations and analogue experiences, for this micro-locality. Smaller number of values refer to other zones in both diagrams, which is completely expected and pointed out by Robertson in his researches. Based on the conducted tests, a classification was done according to the consistent condition of the soil material, in accordance with Larsson and Mulabdic's method, based on piezocone tests of sensitive fine-grained soils. A preliminary conclusion can be made with this method about the bulk weight of the tested material, which in this case ranges between γ=12.7÷14.7 kN/m3 (Figure 7).

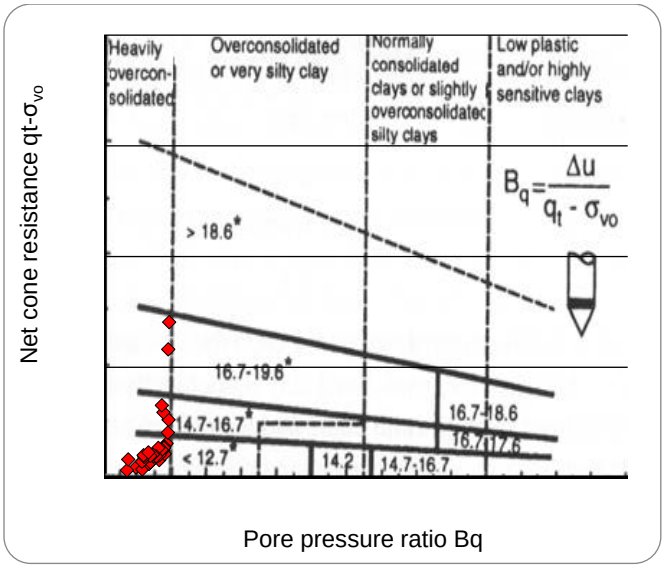

Figure 7. Chart of soil classification from CPTu test, by Larsson&Mulabdic

From the conducted tests and analyses, and with the purpose of choosing a suitable construction system, it can be said that the soil under the surface of the future platform on which the timber piles needed for the authentic reconstruction of the settlement are to be placed, has extremely weak geotechnical characteristics to a depth of 4.2-10 m.

4 AUTHENTIC RECONSTRUCTION OF THE TIMBER PILE SETTLEMENT

4.1 Materials for execution of the pile settlement

According to the requirements imposed by the Institute for Protection of Cultural Heritage, the complete reconstruction of the settlement was to be authentic. This entailed use of the equivalent materials used in its original construction. The underwater archaeological investigations determined the use of piles made of oak wood, with a diameter of 15-30 cm.

Considering the extreme atmospheric influences, constant influences of water, as well as the fluctuation of the water level during the period of exploitation of the piles and the above-water platform, it was necessary to subject these materials to impregnation. Thus, it was decided to use a method of impregnation of the wood, by a procedure including the use of vacuum and pressure in special closed devices – autoclaves. It is important to mention that particular care was taken in the choice of means for this process, in order for it not to contaminate the environment and not to be toxic for the wildlife in the surrounding where it takes place.

4.2 Execution and technical characteristics of the construction

In coordination with the Institute for Protection of Monuments of Culture, it was decided the platform of the pile settlement to be positioned near the site where the remains of timber piles and other archeological artifacts were found. The dimensions of the reconstructed platform, on which the museum is set, are 25 x 42 m and it is placed on 1012

timber piles. These are placed in 25 rows at an average axial distance of 1.0 m, with a diameter of 20 cm, in coordination with the main project for execution of the construction. According to the geotechnical investigations and the lithologic structure of the terrain, it was determined to drive the piles into the base rock material, as end bearing piles, in order to avoid the possibility of differential settlements of the platform. Possible flooding was taken into consideration in determining the length of the piles, besides the lithologic structure of the terrain. The piles are positioned 2.0 m above the surface of the lake in order to avoid flooding of the platform due to fluctuation of the water level or waves. Therefore, piles with length of 6.0-12.0 m were chosen, which were supposed to be driven into the base rock material and which were to penetrate it to a minimum depth of 0.5 m. The depth of penetration is depending on the conditions extent to which it had degraded in the upper parts. Piles placed in this way, with a varying depth, adapted to the field conditions, were hydraulically driven through the soil material with height of 1.2-5.7 m (Figure 8).

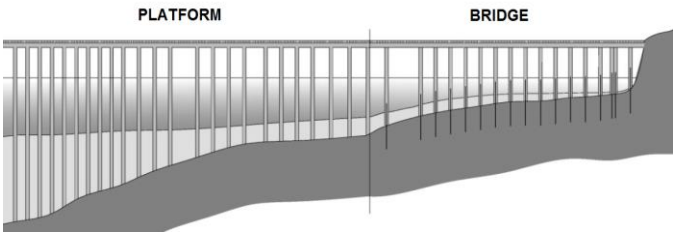

Figure 8. Cross section of the timber pile settlement

Additional type RTS vibratory equipment was used for overcoming the friction resistance on the surface of the piles, in the process of their driving through the soil material at the bottom of the lake. In the upper part these piles will be connected to wooden beams, also made of oak, in order to ensure greater rigidity of the entire construction system, in case of horizontal or vertical load.

The length and position of the bridge which provides a passage between the shore and the platform, was chosen based on the remains of piles nearest to the shore of the lake as well as on their schematic positioning, also determined with the underwater investigations. In accordance with this, the wooden bridge with a length of 19.0 m was anchored in the shore in order to prevent any horizontal movements of the platform. In the execution of the bridge, 68 piles were placed in 17 rows at a distance of 1.0 m.

Figure 9. Preview of the authentic reconstruction of timber pile settlement

The execution and the driving of the piles from the reconstructed pile settlement, took place in specific conditions, in the waters of the Ohrid Lake. For this purpose, a floating barge was brought and mounted by means of a special transport. The dimensions of the platform are 7.5 x 17.0 m, and its capacity allows for unobstructed functioning of the machinery with a weight of 25-30 t.

5 CONCLUSION

North Macedonia is great mine of cultural and historic inheritance; therefore, projects of this type should become common activities in government's projects for promoting tourism and cultural legacy. The Museum on water represents an authentic reconstruction of a settlement from the Iron and Bronze ages, and it is a tourist attraction for Macedonia but also for many visitors from abroad. All the materials used in this construction, as well as the means used in the process of testing and research are from natural material, in order to preserve the natural environment and not to harm the existing flora and fauna.

The role of geotechnical engineering in preservating this historical monument took major part in the whole project. The investigations as well as the planning, designing took essential part in the authentic reconstruciton of the whole project.

Just a few meters from the shore is the passage, not only for a simple settlement, but a passage for a real time travel experience of tourists from all over the world that will find themselves right in the prehistoric times.

REFERENCES

1. Baldi, G., Belotti R., Ghionna V.R., Jamiolkowski M., Lancellotta R., Robertson P. K, (1989) "*Shear strength of sand from CPT*", Proc. 12th ICSMFE, Rio de Janeiro, p.p. 165-170.
2. P. K. Robertson, J. J. M. Powell (1997). "*Cone Penetration Testing in geotechnical practice".*
3. M. Sachetto, A. Trevisan (2005). „*CPTs executed in dificult conditions using CPTWD and its future developements*"
4. P. K. Robertson, K. L. Cabal 5th edition (2012). „*Guide to cone penetration testing"*
5. P. Kuzman, E. Kochkovska, M. Sekulovski (2010). „*Museum on water, Bay of the Bones, reconstruction of pile dwelling settlement*"
6. R. Poulsen, B. N. Nielsen, L. Bo Ibsen (2011). „*Field cone penetration tests, with various penetration rates-Tests results*"
7. H. Gjorgjevski, S. Suvaka, B. Veljanovski, D. Nikolovski, A. Stojkovska (2009). „*Main Project for authentic reconstruction of palafitte settlement on timber piles „Bay of the Bones" (in Macedonian).*"
8. K. Bahchevandziev, Gj. Gruevski (2009). „*Methods of improving the quality and impregnation of oak tree exposed on extreme atmospheric influences, (in Macedonian)*"
9. Schanz T., Vermeer. P. A. (1996): "*Angles of friction and dilatancy of sand*", Geotechnique vol 46 (No.1), pp. 145-151
10. Terzaghi, K. (1967): "*Soil Mechanics in Engineering Practice",* John Wiley and Sons
11. Terzaghi, K. (1936): „*Theoretical Soil Mechanics*", John Wiley and Sons, Inc. New York