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IN-SITU DETERMINATION AND NUMERICAL MODELLING OF AXIAL CAPACITY OF PILES IN GRAPHITIC SCHISTS

This paper presents the analysis of results of static pile load testing for determining the axial capacity of pile foundation carried out in graphitic schists. While multiple tests have been made on the pile foundations of the viaducts, this paper will only present the process of pile load testing carried out on a single pile, with a length of 16 m and diameter of Ø1200 mm, whereas the analytically estimated load capacity is set to 9 MN. A unique steel platform as reactive system has been designed in order to provide a counter load for the downward forces applied during testing. The results show that the deformations of the pile under the effect of the designed loads are minor in comparison to the allowable ones foreseen in the design. In order to model the ultimate bearing capacity of the pile foundation, numerical modeling has been made by calibrating the model for the loads applied during the test and an assessment of the ultimate axial capacity of the pile.

Keywords: static pile load testing, pile foundations, interaction, axial pile capacity

1. INTRODUCTION

This paper presents the methodology used in determining the pile bearing capacity carried out in graphitic schists on the A2 state highway project (Kichevo – Ohrid). The choice of the constructive system depends mainly on the geotechnical conditions, which are a result of highly complex and long-lasting effects of the geological structure of the terrain, hydrological, hydro-geological conditions, seismicity, the morphology of the terrain and other influences, which in an inherent way affect the stability, deformability and bearing capacity of the substrate. Exceptional attention is channelled towards the analysis of the results from the experimental direct measurements on site, with a uniquely designed reactive steel platform system that acts as a counter load for the downward loads applied. The input parameters for the analysis are different, generally depending on the characteristics of the structure, the load levels, the foundation depths, the parameters of the substrate, the dimensions of the foundation and other structural characteristics. The entire process includes: analysis of the terrains geological profile, design of a reactive system that is further on used as a counter load during the test, a defined methodology for load application, on site measurements, reporting the results and calibration with numerical modeling.

2. ON SITE CONDITIONS AND DESCRIPTION OF THE STRUCTURE

The structure is a viaduct bridge from the Kichevo – Ohrid highway project, near the village of Lavchani near Kichevo. It was constructed with the balanced cantilever method, with a pile foundation system consisting of 56 piles connected with a pile cap, with dimensions of 23.6 x 31.0 m. Pile no. 16 of pillar P2 (Figure 1), has been chosen as a representative test pile, with a length of 16 m and diameter of Ø1200 mm. The design axial capacity of the pile is 9000 kN.

According to the geotechnical investigations report, as well as the technical report of the pile, the geotechnical profile of the terrain is defined with graphitic schists fractured at surface, filled with clayey material and a thickness of 0.5 m, under which there is a homogeneous medium composed of carbonate-graphitic schists with extremely high strength, up to the investigated depth of 30 m (Figure 2). Figure 3 shows a panoramic view of the construction site, as well as the complex geological and geotechnical conditions in which the construction activities are carried out.

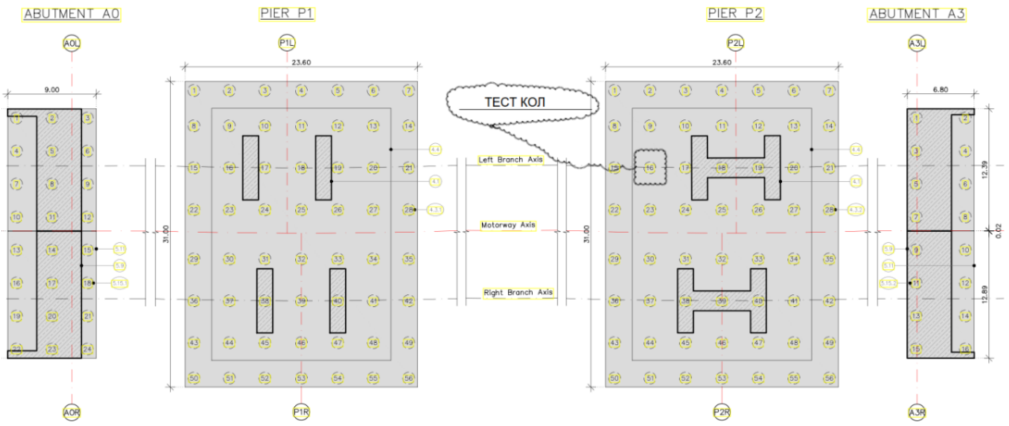

Figure 1. Position of the test pile in pile foundation

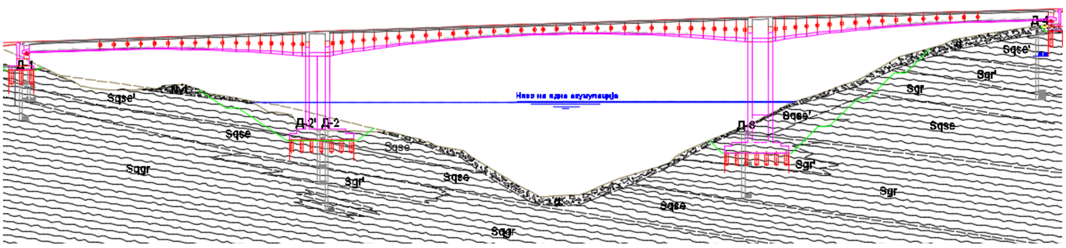

Figure 2. Longitudinal geotechnical profile of the viaduct

Figure 3. Panoramic view of the construction site and geological conditions

3. COUNTER LOAD REACTIVE STEEL PLATFORM

According to the design documentation, the axial pile capacity is 9000 kN. According to the National technical regulations book for the design of foundations, but also the recommendations of EN1997, ASTM and other regulations, it is mandatory to apply the maximum designed load on the test pile. For this purpose, a steel platform of cross beams has been designed that will connect four adjacent anchor piles loaded in tension. This type of structure forms a reactive system with a sufficient capacity to receive the loads with which it is necessary to load the test pile during the test (Figures 4 and 5).

4. METHODOLOGY

The testing procedure is carried out in accordance with the ASTM 1143D/1143M-20 standard. A standard procedure with three levels of loading and unloading was implemented, according to a previously defined Program. The load is applied using a system of 10 hydraulic load cells, with a unit capacity of 1000 kN (or 10 x 1000 = 10,000 kN). In accordance with the practice and standard procedure, the hydraulic cells are carefully placed on a special steel support plate that is positioned on the head of the test pile. The presses are connected with hydraulic hoses with an installed measuring instrument through which the total pressure in the entire load applying system is controlled. Because the hydraulic cells are connected to a single system, through a suitable distributor, when the hydraulic oil is pumped, they simultaneously apply the force on the platform and the cross beam reactive system and thus on the pile itself. Monitoring the test pile settlement under the effect of the applied load is carried out through three digital strain gauges that are place axisimmetrically on the lower special cover plate. The results for the applied load and test pile deformations are monitored with appropriate equipment during the testing.

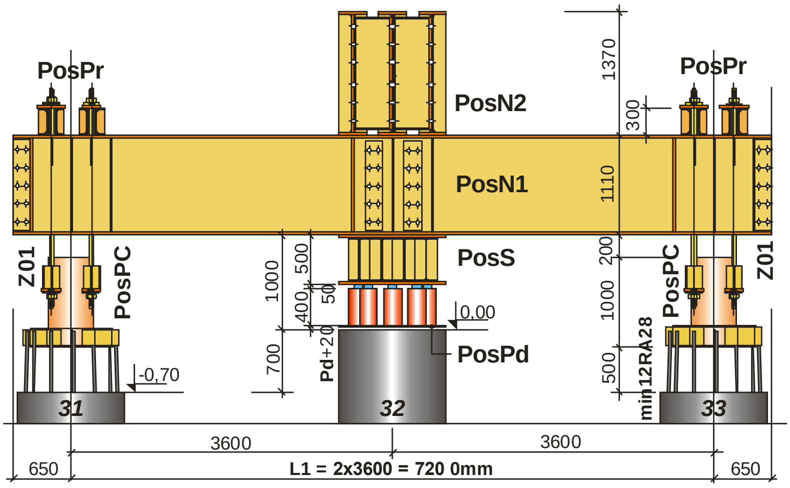

Figure 4. Cross section of the counter load steel platform reactive system

Figure 5. View of the cross beam reactive platform system during testing

5. TEST RESULTS

In accordance with the program, in the first load cycle, the test pile is loaded with a force equal to 50% of the design estimate (4500 kN), with a load application step of 10% (900 kN). The pile deformation criteria must be satisfactory (< 25 mm in the past hour of testing), in order for the test to proceed on to the next step of loading. The unloading down to 900 kN is performed with a 10% load reduction step. The next load increase is set to 6300 kN, followed by a reduction of loading force to 900 kN. The final load is set to 9000 kN and unloading to a load force of 0 kN (Figure 6). The first cycle of loading the test pile to 4500 kN has been reached within 350 min, the second cycle of up to 6300 kN in 560 min and the third cycle of 9000 kN in 880 min. The load – settlement curve is shown in Figure 7. In the first loading cycle, approximately 0.96 mm of settlement is reached, followed by a load decrease with recorded elastic deformation of about 0.40 mm. The second loading cycle is performed to a force of 6300 kN, during which a settlement of 1.27 mm is reached. This implies a settlement increase of 27%, with a loading force increase of 40%. Hence, the trend of increasing deformations and the non-linear character of the material behavior through strengthening can be clearly perceived. After this, the second unloading cycle was applied with plastic deformations of 0.65 mm. In the third and final cycle, there is a deformation of 2.08 mm. This implies that with an increase in loading force of 43%, the deformations, that is, the test piles settlement is increased by 63.8%. Figure 8 presents the time dependence of the settlement, which is still significant in determining the yielding point and the maximum limit deformations of the pile-soil interaction system. The measured maximum settlements of the three loading cycles for the test pile are given in table 1.

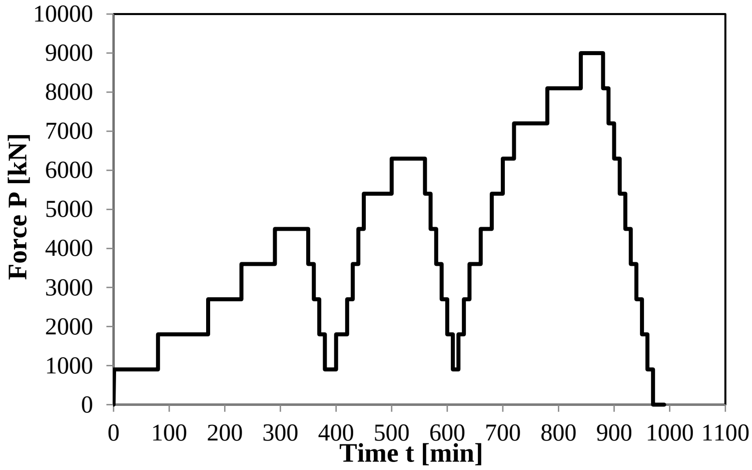

Figure 6. Diagram of the test loading force and time

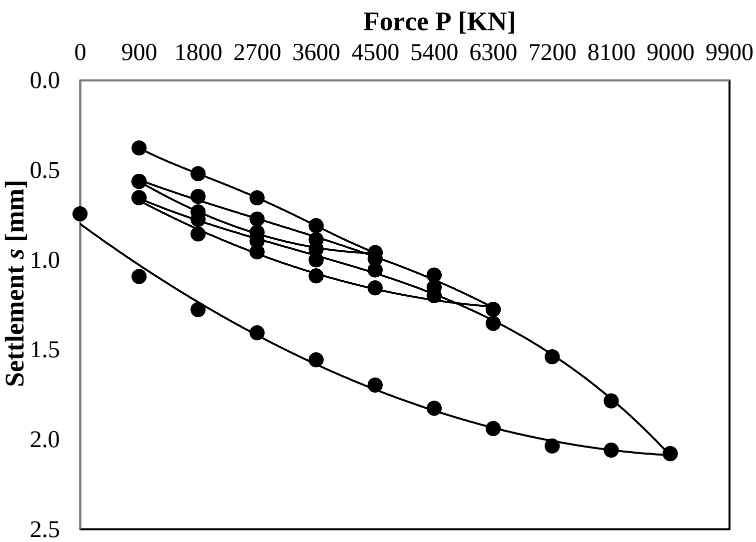

Figure 7. Load-settlements curve of test pile

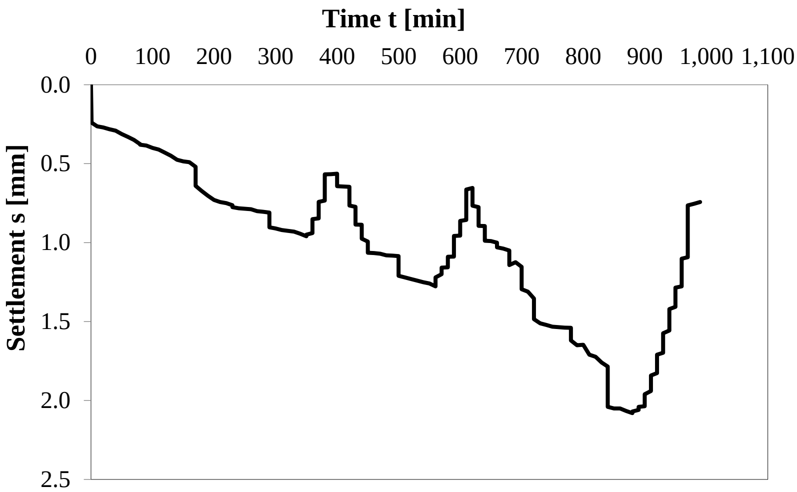

Figure 8. Time-settlement relationship

Table 1. Display of maximum applied force and settlement per load cycle

Loading cycle	Force [kN]	Settlement [mm]
I	4500	0.96
II	6300	1.27
III	9000	2.08

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It is evident that the design loads cause very low settlements, which only confirms the axial capacity of the pile, which is higher than estimated in the design documentation. This case is probably due to the underestimated material characteristics of the rocky, i.e. semi-rocky material and the fact the pile foundation type is end bearing piles. According to the standards and positive practice in the country, the allowable settlements for such a structure, with a statically indeterminate system, must not be greater than 50.0 mm or as a differential less than 5.0 mm. In this case neither one of the criterion is reached, which implies that the piles are loaded with a force significantly lower than their ultimate bearing capacity.

6. TEST RESULTS

The main objective of the numerical modelling is based on a pre-calibrated model for loads up to 9000 kN, in order to estimate the axial bearing capacity of the pile, having in mind the impossibility of loading the pile with forces close to the ultimate capacity.

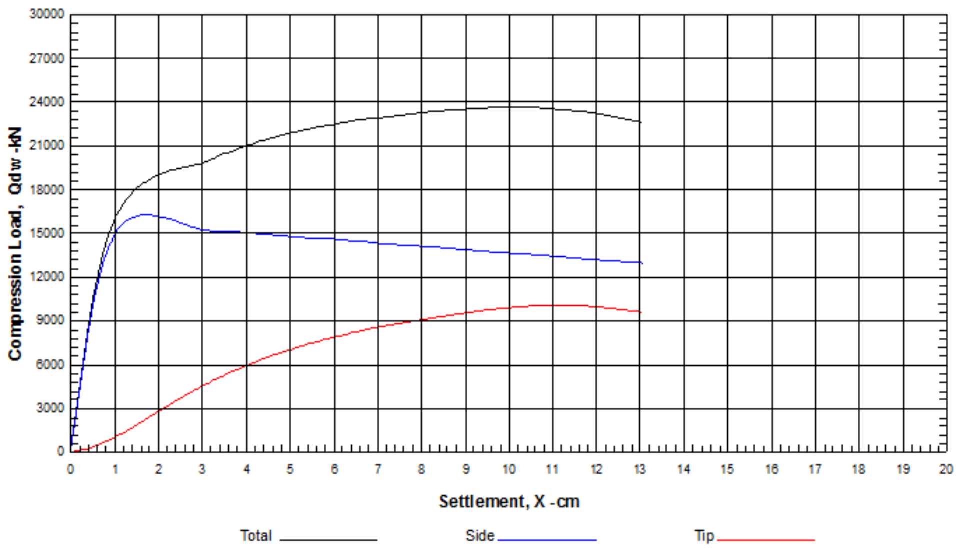

Figure 9. Load-settlement relationship obtained in AllPIle 6.5 software (red: pile base resistance, blue: pile shaft resistance, black: total pile resistance

In the first step, the geotechnical model is calibrated in the AllPile 6.5 software, i.e. reverse analysis for obtaining the physical-mechanical and load-deformation parameters, that will give a maximum settlement of the pile of 2.08 mm. It was confirmed that the parameters were in the limits of those defined in the design documentation and they are: γ=25 kN/m^3, φ=32°, c=200 kPa, E=3000 MPa, k=100000 kN/m^3, υ=0.3. Figure 9 shows the dependence between the settlements and the axial load on the pile, divided into base bearing capacity and bearing capacity along the piles shaft. The total ultimate force is estimated at 23625.84 kN.

7. CONCLUSION

According to the methodology of determining the axial pile bearing capacity in soft graphitic schists, through the procedure of static pile load testing, the ultimate axial load capacity is determined. From the 16-hour testing period of the pile and from the result analysis, it can be concluded that the design loads cause relatively small settlements, lower than the estimated ones within the design and the allowable ones in accordance with the positive practice of testing for such structures, as a statically indeterminate system (SIS). The piles are loaded with a force lower than their bearing capacity, which is also an imperative in the structural design. In order to estimate the reserve and the ultimate bearing capacity, numerical modelling is done by calibrating the parameters of the substrate with the settlements obtained during testing, where an ultimate force of 23.625,84 kN is obtained. For more precise results that will refer to the entire pile foundation, it is recommended for a 3D numerical analysis to be done, taking into account the interaction of the upper (above ground) structure and pile foundation with the surrounding environment.

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