DOI: https://doi.org/10.68732/ba50a97b7821aca7

ISBN: 978-9989-2053-7-8

Comparative assessment for prediction of settlements for piles in weak rocks: Case studies

S. Abazi, S. Gjorgjevski, J. Josifovski & B. Susinov
University Ss. Cyril and Methodius, Faculty of Civil Engineering in Skopje, MKD
sead@gf.ukim.edu.mk
0000-0001-8263-600X

Abstract

This article aims to assess settlements and the load-bearing capacity of piles through experimental and numerical analyses in specific weak rock materials with pronounced anisotropy and heterogeneity.

Thereby, extensive program of field tests was performed with a special system for receiving load through the use of a specially designed platform that serves as a counter load with capacity up to 9000 kN.

The results from two case histories are presented. First case is related to bridges and galleries with large dimensions. The structures are foundered in weak rock mass composed of schists formation present on sections at Macedonian highway from Kicevo to Ohrid. Second one is related to underground excavations in an urban area in Capital Skopje, where the structures are foundered in marls.

From the analysis of a number of experimental tests of piles to the designed or ultimate force, a typical load - settlement curves are presented. Results indicates that the piles constructed in shist formation, even with a poor rock mass quality, shows that the limit state of failure is not reached for the maximum applied designed loads. From the other case, structure foundered in marls shows completely different mechanical behaviour.

As a result of the analyses, some correlations between the examined parameters were established, and findings from all analyses are used to establish some correlations between settlements and rock mass quality defined with some known rock mass systems as Qc. Some ideas for further development of the methodology are underlined.

Keywords

Field experiment, Geotechnical model, Static load test, Weak rocks, Piles.

1 Introduction

The problem of definition for range of settlements and bearing capacity in weak rock masses can be important for some cases of when certain structure transfer a high load to the rock mass.

For the topic of the article, several approaches are important. Interesting analyses for the settlement behaviour so single axially loaded piles and piers are presented long time ago (Poulos, H.G. & Davis, E.H. (1968).

A particularly significant emphasis is placed on the application of diverse in situ testing methods for determining the bearing capacity of deep foundations. Notable contributions in this regard have been made through the American or British Standards (ASTM D4945-12; ASTM D1143; ASTM D5882-07; ASTM D7383-10). Laboratory methods and instruments for geotechnical testing, aimed at defining the physical–mechanical parameters of natural and artificial materials involved in interaction processes, have been developed by numerous researchers. Related to this, highly relevant are suggested method presented by ISSMFE subcommittee on field and laboratory testing related to axial pile loading test (1985). An interesting approach to load testing of high-capacity piles is presented by Bermingham and Janes (1989).

A particular focus on defining deformability and shear strength of soft rock masses through empirical failure criteria was provided by Hoek and Brown. Their methods were later extended to weaker rock types and further advanced through the development of new classification systems based on the Geological Strength Index (Marinos and Hoek, 2000). Critical issues in soft rocks are addressed in works by Kanji (2014), while development of an approach to define properties of hard soils-soft rocks are presented by Kavvadas in his general report at XV European Conference on Soil Mechanics and Geotechnical Engineering (2011).

Systematic presentation for using of classification methods in solving of some engineering problems in rock masses are explained by Barton (2018).

A problem of data extrapolation in weak rock masses is of particular interest when dealing with larger volume of rock mass is presented using Empirical – Static - Dynamic (ESD) methodology for extrapolation in rock mechanics (Jovanovski et al, 2018).

Despite wide range of articles and methodologies, it is always good to present some findings from detailed field tests, because the data can be helpful in engineering estimations of settlements in weak rock masses. Having this in mind, in a frame of article, the results from two case histories are presented. First case is related to bridges and galleries with large dimensions. The structures are foundered in weak rock mass composed of schists formation present on sections at Macedonian highway from Kicevo to Ohrid. Second one is related to underground excavations in an urban area in Capital Skopje, where the structures are foundered in marls.

The results are systematised and presented in a form of correlation between rock mass quality parameters and settlements, in order to serve as a tool for prognosis for range of settlements that can be expected.

2 Methodology of work

The methodological approach is based on several main principles. More precisely, in defining the subject of research within the article, an attempt was made to adopt a comprehensive approach, employing an appropriate scientific framework that integrates theoretical, experimental, and further numerical modeling of the natural environment as the foundation medium.

For testing, the steel reaction system was designed to accommodate different pile axial spacings. The platform was conceived as a universal system. For the selection of the required dimensions and the design of its structural components, several pile arrangements of individual foundations at three test locations were analyzed (Figure 1). The platform girders were designed for maximum spans of L_1/L_2 = 10.0/10.0 m and for a maximum test load of N = 9000 kN. All tie members and structural components used for transferring the test load to adjacent piles were designed for a maximum tensile force (negative reaction in the neighboring piles) of ΣZ = 2450 kN. The maximum tensile capacity of the

ties was defined based on the pile pull-out resistance (approximately 4000 kN), applying a safety factor F = 1.70.

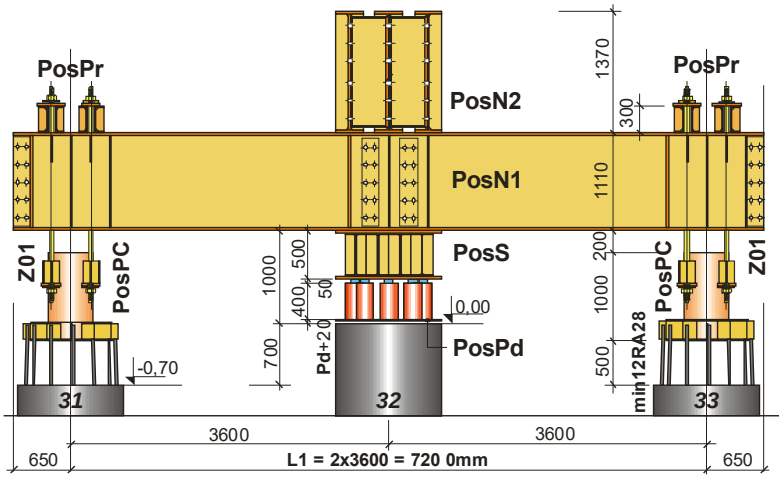


Fig. 1 A details for steel beam loading system used for testing.

As a basic data input, some results from extensive program of field tests were performed.

Photo of testing system at one of the locations is presented in Figure 2.



Fig. 2 Photo of the system at the test location of the Kičevo–Ohrid motorway bridge "Dobrenoec".

Testing program was usually applied using several phases of loading and unloading. The testing procedure is presented in Figure 3.

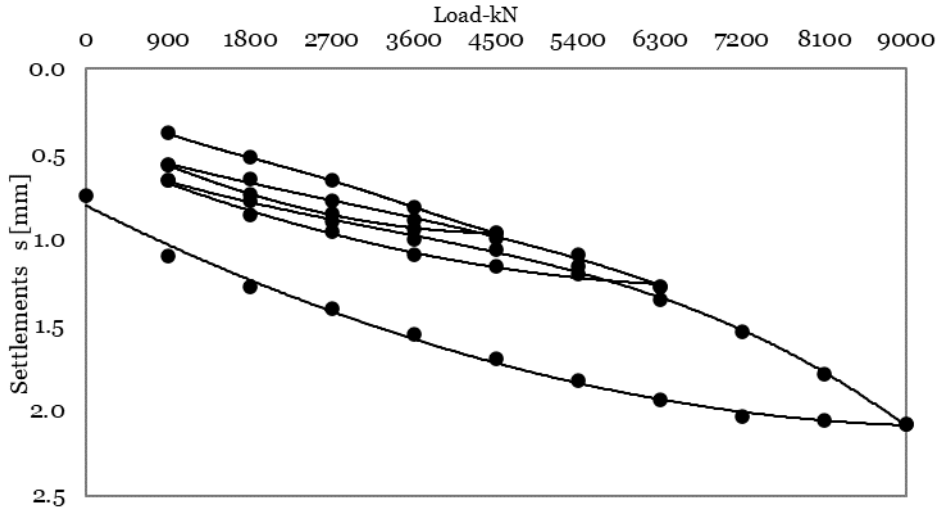


Fig. 3 Testing procedure applied at the Kičevo–Ohrid motorway bridge "Dobrenoec".

The data basis for further analyses is insured from several locations, testing different soil and weak rock formations, but in a frame of the article, only data for weak rock mass formations are presented.

3 Results and discussion

The range of observed settlements for applied level of load is presented in Figure 4.

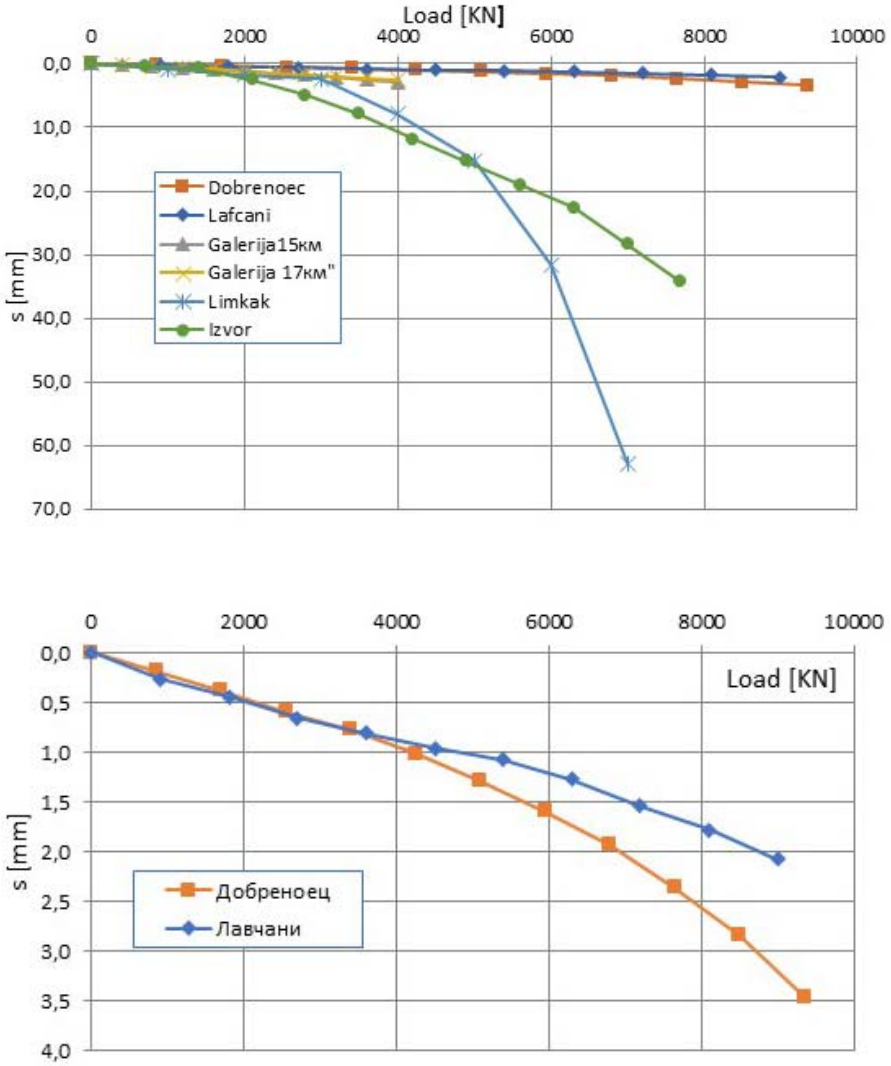


Fig. 4 Results for typical load-settlements curves for several tested locations (lower Figure section is only with curves for testing locations in weak metamorphic schist's complex, in order to see the different range of settlements).

The load–settlement curves in Figure 4, labeled "Dobrenoec," "Lafcani," "Galerija 15 km," and "Galerija 17 km," correspond to structures along the Kičevo–Ohrid highway founded in schist formations. The curve "Limkak" represents a structure founded in marls, while "Izvor" illustrates the response of dense gravels. These latter curves are included to highlight the contrast between settlements in soils (gravels) and weak rocks (marls), compared with the behavior of schist complexes composed of graphitic or sericite schists.

Given that such large-scale field tests are difficult to perform at every site and across diverse geotechnical zones, rapid methods for forecasting expected deformations are essential. In this context, established classification systems can provide valuable guidance. For example, Hoek et al. (1998) laid the foundation for the Geological Strength Index (GSI), and Kavvadas (2011) proposed modifications to adapt GSI for weak rocks in tunneling. Barton has advanced various versions of the Q-system, with engineering applications discussed in his 2018 lecture (Barton, 2018).

The present study applies a modified Qc classification, incorporating corrections for Uniaxial Compressive Strength and correlating these with measured settlements from field tests. The

formulation of Qc method is presented in Equation 1 (Barton, 2018), with supporting data summarized in Table 1.

$$Qc = [(RQD/Jn) * (Jr/Ja) * (Jw/SRF)] * (UCS/100) \quad (1)$$

Where: Qc-Normalised quality index for compressive strength,

RQD	Rock quality designation index
Jn	Joint set number
Jr	Joint roughness number
Ja	Joint alteration number
Jw	Joint water reduction factor
SRF	Strength reduction factor

Table 1. Data for Qc and settlements for analysed cases.

Location/ rock type	**RQD/Jn**	**Jr/Ja**	**Jw/SRF**	***UCS/100***	***Qc***	***S mm (1)***	***S mm (2)***	***S mm (3)***
Limak/marl	60/12=5	1/4=0,25	1/5=0,2	2,5/100=0,025	0,00625	1,81	2,45	7,87
Dobrenoec/Sgr	50/9=5,55	1/3=0,33	1/5=0,2	15/100=0,15	0,055	0,42	0,82	1,12
Lafcani/ Sgr	45/9=5	1/3=0,33	1/5=0,2	25/100=0,25	0,083	0,27	0,67	0,96
Gallery 17	40/9=4,44	1/3=0,33	1/5=0,2	15/100=0,15	0,044	0,56	2,15	2,87
Galerry 15	40/9=4,44	1/3=0,33	1/5=0,2	20/100=0,20	0,058	0,51	2,01	2,53

Note- Smm (1) – mesaured settlements for load 2000kN; Smm(2)-for load 3000 kN; Smm(3)-for load 4000 kN.

The results clearly demonstrate the distinctive mechanical behavior of marls: once the applied load exceeds 5000 kN, settlements increase rapidly, reaching more than 60 mm. In contrast, schists do not reach ultimate capacity under the applied loads, with settlements remaining in the range of 2–4 mm. Based on the analysis of the results, it can be observed that, depending on the geological environment, the type of structure, the foundation system, and the level of applied load, settlements occur over a certain range, governed by the interaction of the components within the rock–structure system. The natural characteristics of the foundation media, can be defined by classification and characteristic parameters of soil or rock media, strength and deformability parameters, or by an overall assessment of the 'geological quality' of the ground with adequate messurements. The characteristics of the structure itself, including its height, width, and other geometric dimensions, determine the magnitude of the load applied to the natural media. Combining data, several correlations can be established, and some of them are presented in Figure 5.

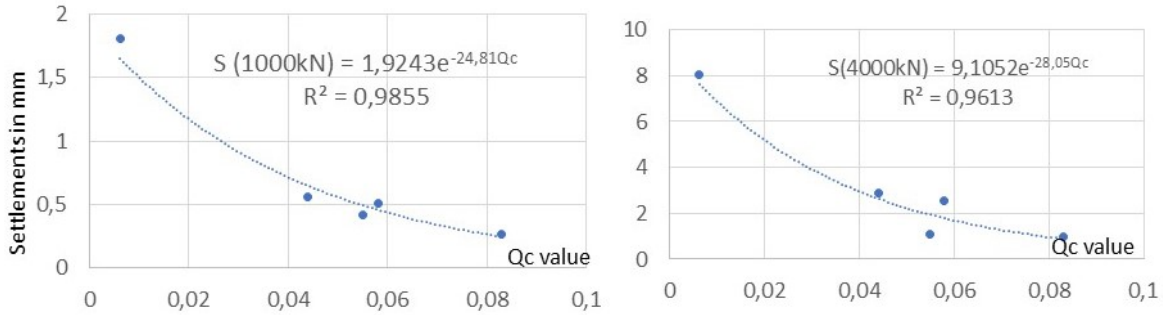


Fig. 5 Correlations between range of settlements for different level of load versus quality index Qc.

Despite relatively small number of points for correlations, it is evident that some kind of extrapolation of such data in larger scale volume using classification parameters and correlation with range of longitudinal seismic waves. When geophysical testing results are available, the Empirical-Static-Dynamic method can be applied (Jovanovski et al, 2018). This overcomes the frame of this article and it will be a subject for further analyses.

4 Conclusions

The findings presented underscore the importance of applying multiple methods in a comparative manner and establishing correlations among the examined parameters. Such an approach highlights the practical dimension of the problem: the foundation of specific structures is a daily reality in engineering practice, and every scientifically grounded procedure must ultimately yield actionable guidelines for application.

To address the variability of physical and mechanical properties in foundation grounds-whether soil or rock-this study attempted a comparative assessment of interaction effects.

These findings can be a useful framework for future research, particularly as a tool for improved load-settlement prediction during the conceptual design stage.

References

ASTM D5882 – 07 Standard Test method for Low Stain Impact Integrity Testing of Deep Foundations.

ASTM D4945-12 Standard Test Method for High-Strain Dynamic Testing of Deep Foundations.

Barton N. (2018) A Career in Rock Mechanics and Rock Engineering – a choice you will not regret, Youth Forum Event, ISRM, St. Petersburg, May 2018

Bermingham P., Janes, M., (1989). An innovative approach to load testing of high-capacity piles. Proceedings of the Internecinal Conference on Piling and Deep Foundations, London, pp 409-413.

British Standard, London 1995. Code of practice for strengthened/reinforced soils and other fills, British standards Institution.

Hoek, E., Marinos, P., Benissi, M., 1998. Applicability of the geological strength index (GSI) classification for very weak and sheared rock masses. The case of the Athens Schist Formation. Bull Eng Geol Environ (1998) 57, pp 151-160.

ISSMFE. Subcommittee on Field and Laboratory Testing, Axial Pile Loading Test, Suggested Method, ASTM Journal, Vol. 8, No.2, 1985, pp. 79-90.

Jovanovski M., Pesevski I., Papic J. Empirical – Static - Dynamic (ESD) methodology for extrapolation in Rock Mechanics, Geomechanics and Geodynamics of Rock Masses – Litvinenko (Ed.) © 2018 Taylor & Francis Group, London, ISBN 978-1-138-61645-5

Kanji M.A. (2014). Critical issues in soft rocks, Polytechnical School, University of São Paulo, Journal of Rock Mechanics and Geotechnical Engineering 6 (2014) 186-195

Kavvadas M., Tunnelling in Hard Soils – Weak Rocks (HS-WR) SESSION 5 (2011): Excavations and Tunnelling. General Report, XV European Conference on Soil Mechanics and Geotechnical Engineering, Athens, 2011

Marinos, P., Hoek, and E., (2000): GSI: A geologically friendly tool for rock mass strength estimation. Proceedings of the International Conference on Geotechnical & Geological Engineering (GeoEng 2000), Technomic Publishing Co. Inc., Melbourne, Australia, pp 1422-1440.

Poulos, H.G. & Davis, E.H., (1968) 'The settlement Behaviours of Single Axially-Loaded Incompressible Piles and Piers'. Geotechnique, Vol. 18: 351-371.