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Dimensional Specifications and Resistance Characteristics of Olive Marl Masonry for Reinforcement and Stabilization of Excavations and Road Structures

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Our study focuses on the challenges of preserving excavations and adjacent structures and stabilizing soil walls in construction projects. Neglecting appropriate protective measures can lead to settlements, instability, and alterations in the surrounding area. To address these issues, the use of retaining walls with soldier piles is recommended due to their simplicity, compatibility with different ground conditions, and adaptability to limited spaces. The manuscript presents investigations into the behavior of soldier pile walls, particularly in cohesive and marl soils. Numerical analyses and laboratory experiments were conducted to assess their performance. The

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research demonstrates the effectiveness of soldier pile walls in various construction operations, including highway construction, foundation excavation, and retaining walls for excavations. It also highlights their success in stabilizing slopes, embankments, underground structures, and protecting temporary and permanent retaining systems.

Marl soil, a sedimentary rock composed of clay and calcium carbonate, presents unique challenges due to its high plasticity and semi-rigid behavior. The manuscript emphasizes the importance of understanding the behavior of piles in marl soils and improving the performance of soil nailing systems. The study examines the impact of different drilling methods on the behavior of soldier piles in marl soil, with a focus on rotary drilling with standard cement grout. The findings reveal increased tensile strength in piles installed using this method compared to percussive drilling. The research provides valuable insights for engineers and practitioners, contributing to efficient land utilization in urban areas.

Overall, this research offers valuable knowledge for the construction industry in dealing with challenging soil conditions. It provides a foundation for developing improved design approaches for excavations and adjacent structures, particularly in cohesive and marl soils. The findings highlight the effectiveness of soldier pile walls and emphasize the need for understanding marl soil behavior to enhance the performance of soil nailing systems. Further research is encouraged to validate the results for different marl soils and explore additional strategies for improving the tensile strength and long-term behavior of piles in these conditions.

Keywords: Marl; soil nailing; creep; tensile strength; drilling type.

1. INTRODUCTION

Excavation and stabilization of nearby structures pose significant challenges in civil engineering during building construction. Without employing suitable protective measures, various issues and potential risks can arise, including settlements, instability, and alterations in the surrounding area [1,2]; (Suzan et al., 2019). Such consequences may lead to damages, accidents, increased traffic, and disruptions, particularly during peak hours. To address these risks and promote safer construction practices, engineers are increasingly adopting more innovative approaches, like Active Traffic Management (ATM) policies, to improve traffic network performance while managing costs and time [3,4].

To prevent these occurrences, it is crucial to implement suitable methods, especially before excavation operations commence, to ensure the preservation and lateral support of adjacent structures. In this regard, the use of well-established protective systems is recommended due to their proven effectiveness and advantages over other methods. These advantages include the ability to be implemented alongside existing structures, utilization of connected autonomous vehicles (CAVs) to alleviate the situation, compliance with environmental criteria (e.g., noise and vibration reduction), ease of execution, compatibility with various ground conditions and surface features (including deformability and permeability of soils), and the ability to work in limited spaces [5-8]. By adopting these protective measures and innovative practices, civil engineers can ensure safer construction processes, minimize potential risks, and create a more efficient and sustainable approach to building projects [1,9].

The concept of retaining walls with soldier piles is based on the transfer of tensile forces generated in the reinforced elements. The mechanism of load transfer between the soldier piles and the soil mass depends on various factors, including the final embedment capacity, installation parameters, drilling method, shape of the excavation section, grout consumption, installation technique, and the size and shape of the reinforcing elements. It is important to consider soil permeability and shear strength characteristics in the design and analysis of soldier pile walls, as they affect the interaction between the soil and the soldier piles, as well as the development of tensile forces in the piles [10,11].

Numerical analyses have been conducted to investigate the behavior of soldier pile walls under different conditions, particularly in comparison to conventional methods when dealing with soils requiring high lateral support [10,12]. The use of soldier pile walls has proven to be highly effective in various construction operations, such as highway construction, foundation excavation, retaining walls for excavations, underground structures in urban environments, repairs, strengthening and reconstruction of deteriorated structures, and tunnel entrances. Moreover, it has been successful in stabilizing slopes, embankments, and underground openings, protecting excavations in urban structures, neighboring structures of excavations, metro stations, and the maintenance and protection of temporary and permanent retaining systems. Numerous laboratories, field, and software studies have been conducted to investigate the effects of surcharge, injection pressure, and water pressure on the tensile resistance of soldier piles and the behavior of grouted soils under static and dynamic conditions, yielding significant results [13,14].

Investigating the behavior of piles in cohesive and marl soils, which are fine-grained soils with different properties compared to sandy soils, is an understudied topic. However, it is crucial to address this issue as it involves challenges such as high bending stiffness, semi-rigid behavior, long-term behavior under load, low injectability, and other related factors that require further investigation [7].

In recent years, due to urban growth, population density, increased underground structures, and deeper excavations, the need for efficient utilization of land and its value in urban areas, particularly in densely populated cities, has risen. Therefore, it is essential to identify and implement cost-effective methods that can address these challenges and provide timely solutions. One of the major concerns is the stability of excavations and the creation of soil walls in highways, tunnels, and major arteries, as well as the deep excavations associated with them. The properties of the soil, usually marl or loam, play a significant role in these cases, and studying their behavior is necessary [15,16].

2. MARL SOIL

Marl is a sedimentary rock composed of clay and calcium carbonate. Marl deposits are found in various regions, including the eastern, northern, and southern parts of Tabriz. Marl can be observed in different colors, such as yellow, olive green, brown, and gray. Yellow and green layers are usually found near the surface, while gray marls are found at greater depths. Marl soils are classified as cohesive soils or silts with high plasticity. Their behavior varies depending on factors such as depth, carbonate content, degree of weathering, moisture content, and the presence of organic matter.

Considering the importance of marl soils and their widespread occurrence in Tabriz and the surrounding areas, studying their behavior in response to pile installation is necessary. To conduct tests, precise instruments capable of measuring force, pressure, and displacement are required. For this purpose, a special tension load cell was constructed with a capacity of up to 50 tons, capable of measuring deformations with an accuracy of 0.1 millimeters. It is equipped with a data logger to automatically record data every 6 seconds. Additionally, the mentioned load cell is equipped with a creep lock system to maintain the applied force constant over time. In case of any force deviation, the system allows for adjusting the force by applying and releasing pressure, ensuring a constant force level.

3. TEST OF EQUIPMENT

To conduct the tests, a device capable of accurately measuring and recording force, pressure, and displacements is required. Accordingly, a special tension load cell was designed and constructed specifically for measuring tensile forces up to 50 tons. It also has a displacement measurement capability with an accuracy of 0.1 millimeters. The load cell is equipped with a data logger to automatically record data at intervals of 6 seconds. Additionally, the mentioned load cell is equipped with a creep lock system to maintain a constant applied force over time. In case of any force deviation, the system allows for adjusting the force by applying or releasing pressure, ensuring a constant force level.

The test equipment includes a pressure load cell, a pressure control valve, a relief valve, a hydraulic pressure pump, a USB data acquisition port, a monitoring system (for force, pressure, and displacement), an internal control panel, a base jack, a jack control system, a leveling tool, and a protractor. These components are essential for accurately measuring and monitoring forces and deformations according to FHWA standards and other recognized measurement standards, with a precision of 0.01 millimeters. Two gauges with the specified accuracy were installed to measure the displacements of the pile and the foundation under the load jack. The measurements were taken with high precision over a specific period of time in accordance with relevant regulations and guidelines.

Considering the sensitivity of working in excavation pits and the repeatability of tests, the monitoring system should possess high precision and quality, exhibit minimal vibrations, and be acceptable for use in the specified conditions. The equipment used in this study should meet the requirements for drilling, including the ability to perform both vertical and horizontal drilling at various angles. It should also be capable of injecting grout with a pressure capacity of up to 10 bars. The equipment setup includes primary and secondary mixers for proper grout mixing, as well as specialized tools for grouting. Please refer to Fig. 1 for illustrations of the equipment setup.

4. TEST OF HYPOTHESIS

The small-scale physical modeling of the soil parameters, along with controlled and accurately monitored influences, using a suitable atmospheric model, can provide realistic and reliable outcomes. Considering the studied soil type, which is a new marl, and the fact that the untouched sample of this soil may have inherent issues due to its structure and moisture content, it is crucial to be aware of the potential errors and significant effects that may arise during the investigation using the laboratory approach [17,18,19].

Initially, a square-shaped excavation with appropriate dimensions and necessary depth was made inside the University of Tabriz site to prevent soil erosion. The walls of the excavation were covered with suitable materials to prevent soil erosion. Subsequently, physical, chemical, mechanical, and mineralogical tests were conducted on the excavated soil to gain sufficient knowledge about the site's soil and its characteristics. Based on the obtained results from relevant tests, it was decided to install anchors on the excavation walls to ensure stability. Specifically, for the olive-green marl, only one specific type of marl with known properties was studied. It is important to note that the effect of overburden is not considered in this research. Due to the presence of faults and varying directions in the soil structure, ensuring ease of work and sufficient accuracy in creating consistent conditions for soil samples, executing the anchors was performed in a systematic manner. Necessary experiments were carried out on these anchors in the laboratory scale, considering the studied soil and the inability to use untouched samples. Therefore, the execution of anchors in the real field conditions was necessary to achieve reliable and accurate results. To investigate the effect of different drilling methods on the interface behavior, pull-out resistance, and the shear behavior of the anchors, two common drilling methods, including "continuous flight auger (CFA)" and "down-the-hole hammer (DTHH)," were examined. It should be noted that the study site will be prepared with suitable dimensions and preparation depth, and the excavation walls will be covered with appropriate materials to prevent erosion. Necessary physical, mechanical, chemical, and mineralogical tests will be conducted on the excavated soil [20,21,22].

Furthermore, to determine the installation locations of the anchors, the area will be marked, and an area of 120x120 cm with a thickness of 30 to 40 cm will be excavated, with a 5-inch borehole for drilling the anchors and injection operations. Before installing the piles, the ground level will be raised to protect them from surface water, rainfall, and create a surface for long-term locking operations. The excavation of the vertical piles will be carried out using different drilling methods (chisels and picks), and two horizontal piles with a 15-degree inclination relative to the horizontal plane will be created to investigate the effect of excavation method on the interface behavior, tensile strength, and creep behavior of the piles. The effect of these two drilling methods, chisels and picks, as common drilling methods, will be examined as one of the influential factors in the research. In the continuation of the work, equipment for pile installation, such as a excavator, low-pressure air compressor, and a suitable generator, will be set up to provide the necessary equipment. Additionally, primary and secondary injection equipment and required materials will be prepared. In this regard, six vertical piles will be prepared in the designated research site using boreholes created by 15 cm diameter augers. Moreover, the necessary preparations for drilling and injection of two horizontal piles will be carried out. The work will also involve the installation of necessary equipment, such as an excavator, low-pressure air compressor, and a suitable generator, for providing equipment, as well as the preparation of primary and secondary injection equipment and necessary materials.

Horizontally, with a slope of 15 degrees relative to the horizontal plane, on the southern wall of the site, the end of the piles was prepared and the mouths of the piles were covered with reinforced concrete cushions with dimensions of

100x100 cm. In the middle of the concrete section, flanged plates with dimensions of 30x30 cm and a central hole with a diameter of 5 cm were embedded to provide the necessary conditions for placing the jack and applying the load, preventing excessive and unexpected settlements during the test. It is worth mentioning that the settlements of different sections were measured and monitored accurately using suitable gauges throughout the testing process. After placing the steel bars inside the drilled casings, the ends of the casings were sealed with a length of 15 to 20 cm, and necessary spacers were added at intervals of one meter. Then, according to the planned injection program, the grout was injected into the piles.

Two common drilling methods, namely rotary drilling and percussive drilling, are commonly used in the implementation of piles in the project. Specifically, three piles were installed vertically using rotary drilling and standard cement grout. Additionally, one pile was installed horizontally using percussive (rotational) drilling and standard cement grout. These configurations were subjected to similar conditions. It is important to note that the maximum time interval for using the mixed grout to ensure better performance and bonding according to the relevant standards is 30 minutes [23,24,25]. After the completion of grout mixing, the injection process was carried out smoothly. It should be noted that the time of testing was selected based on the obtained strength of the grout for injection purposes. Therefore, samples were taken from the grout used in the special sample tubes with a diameter of 2 inches for 3 and 7 days. The samples were then tested for shear strength to determine their compressive strength. Once the necessary strength was achieved, the actual field tests were conducted. A visual representation of the grout samples obtained for determining the compressive strength prior to the pile tension test, following the FHWA guidelines, is provided in Fig. 3. The 7-day samples yielded a minimum compressive strength of 200 kg/cm². The supplier of the grout provided the required test values for the pile tension test. Furthermore, utilizing accurate drilling, mixing, and injection equipment, the installation of piles in the marl soil with varying grout consumption was performed. The necessary tests were conducted to determine the tensile strength of the piles in these conditions and evaluate the effect of settlement on the tensile strength. The results of the tests, specifically for samples 1 and 5, are presented in the following Figs. 1-3.

Fig. 1. Aerial image of the study site along with the tension-compression jack and its peripherals. (a) areal images of the study site. (b) The jack system and its accessories installed at the study site. (c) Data logging and pressure calibration device. (d) The interface connecting the jack to the anchor and installation of measurement gauges. Axial displacement of the anchor and the concrete pad settlement

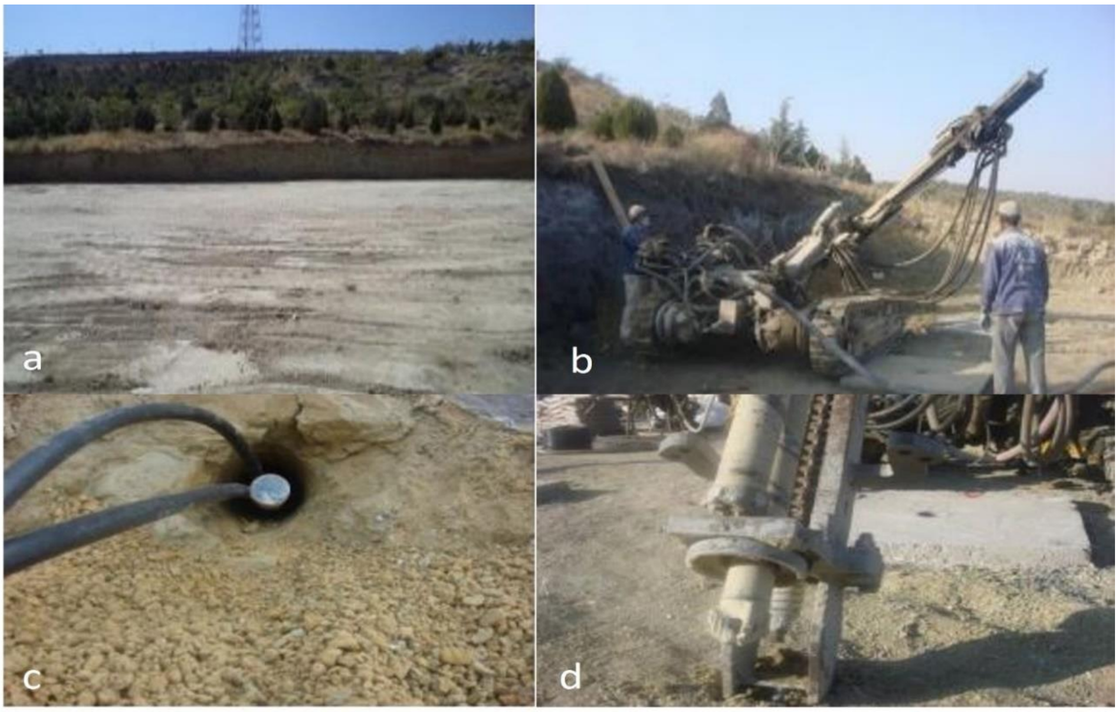

Fig. 2. Site preparation and the method of implementing a reinforced concrete foundation for pile installation. (a) Site leveling and preparation. (b) The excavation machine used in the project. (c) Excavation, placement of reinforcement, and installation of grout injection pipes. (d) The method of using rotary drilling in the project

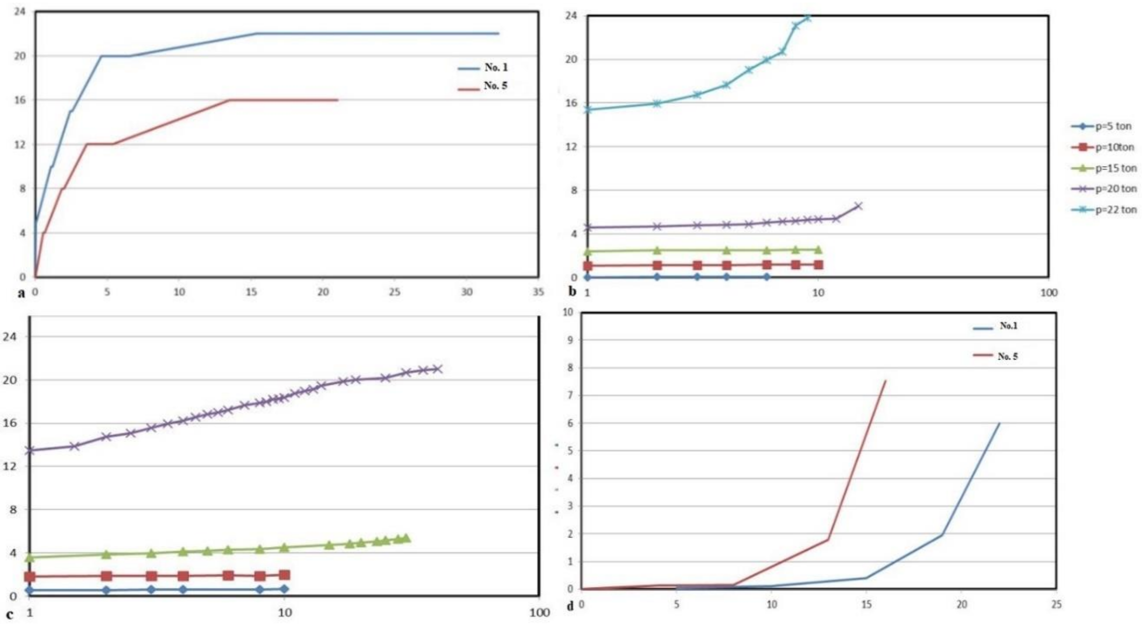

Fig. 3. (a) Diagram of tensile force against axial displacement of the rod until the yielding stage in rods. (b) Diagram of axial displacement of the rod against time under different tensile loads in rod 1. (c) Diagram of axial displacement of the rod against time under different tensile loads in rod 5. (d) Diagram of tensile force against displacement variations in different steps in rods 1 and 5

Table 1. Specifications of olive marl used in construction and its strength parameters

Depth (m)	Density (kg/m^3)	Humidity (%)	Fluidity (%)	Yield strength (%)	Cohesion (kg/m^2)	Internal friction angle (degree)
2	1860	36.6	75	51	1.1	19
4	19001	41	78	60	1.2	20
6	1890	45	80	60	1.3	21

Table 2. Dimensional specifications of piles and grout consumption

Drilling method	Cement grout	Rod number	Final diameter of the rod	Free roll	Injection method roll
Tri-cone bits, percussion bits	Type 2 Sofian cement	32	0.11	0.6 m	4 m

5. RESULTS

The results of the tests conducted using different drilling methods (rotary drilling with air flushing and percussive drilling with air discharge) indicate an increase of 20 to 25 percent in the tensile strength of the piles installed using rotary drilling and standard cement grout injected by gravity compared to the percussive drilling with similar injection conditions in vertical piles. There is also an approximately 15 percent increase in the tensile strength of the horizontal piles [26,27,28]. This could be due to the compaction of marl soil particles caused by the impact and the polishing of the drill section, resulting in better connection and bonding of the grout with the soil. Due to the polishing of the drill section, the separation of cementitious grout from the soil occurs during shrinkage, especially in the upper zone, where there is significant interaction between the two surfaces, leading to an increase in the tensile strength of the piles. The closure of the cavities and fissures in the wall due to the pressure from the percussive blows during drilling also prevents sufficient penetration of the cementitious grout inside and reduces bonding between the two surfaces. This contributes to the improvement of the load-bearing behavior of the piles. The use of both rotary and percussive drilling methods, in both horizontal and vertical orientations, results in undesirable settlements (displacements exceeding 2 millimeters within a certain time period) and indicates a more acceptable long-term load-bearing behavior. Additionally, the influence of lower percussive blows in horizontal piles can be attributed to the settlement and separation of cementitious grout in the upper section of the drilled area [29,30].

6. DISCUSSION

The properties of marl soil and its unique behavioral characteristics, especially in the long term, should be taken into consideration when designing soil nailing systems. The high values of the mobilized coefficients should be carefully considered. Investigations and practical experiences have shown a decrease in the tensile strength of the installed piles in marl soil over time. This can be attributed to the settlement and consolidation of the soil, as well as the movement of water within the soil under applied loads. Therefore, improving the behavior of soil nails in marl soil through various methods and increasing the tensile strength and improving the shear behavior, especially in the long term, is the aim of this paper. Rotary drilling, due to the disturbance in the wall and better bonding of the grout with the soil, can immediately provide suitable conditions for the soil. It can improve the tensile and shear behavior of the pile and enhance its long-term settlement behavior. It is worth mentioning that considering the presence of different types of marl with varying properties, including air and water behavior, and their response to deformation, the results obtained cannot be directly applied to all marl soils. Previous studies on cohesive soils with similar plasticity and compressibility characteristics to marl soils have shown an increase of 20 to 30 percent in the tensile strength of the piles.

7. CONCLUSION

The comparative analysis of rotary drilling with air flushing and percussive drilling with air discharge reveals a distinct advantage of the former in the context of pile tensile strength.

Specifically, piles installed using rotary drilling exhibited an enhancement in tensile strength by 20 to 25 percent for vertical piles and about 15 percent for horizontal ones. This superior performance can be attributed to the compaction of marl soil particles and the polishing effect of the drill section. Such effects promote better grout-soil bonding, especially evident in the upper zones where significant interaction between the two surfaces occurs. The percussive blows during drilling further aid in closing cavities and fissures in the wall, enhancing the overall load-bearing behavior of the piles.

Furthermore, the observed undesirable settlements in both drilling methods underscore the importance of considering long-term load-bearing behavior. The unique properties of marl soil, especially its long-term behavioral characteristics, play a pivotal role in designing soil nailing systems. The observed decrease in tensile strength over time in marl soil is a testament to the dynamic nature of the soil, influenced by factors like settlement, consolidation, and water movement.

Rotary drilling, with its ability to cause disturbance in the wall and foster better grout-soil bonding, emerges as a promising method to enhance both tensile and shear behavior of piles in marl soil. However, it's crucial to note that the diverse nature of marl soils, with their varying properties, means that the results of this study may not be universally applicable. Nevertheless, the findings align with previous studies on cohesive soils, further validating the potential benefits of rotary drilling in enhancing pile tensile strength.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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