

The Behavior of Laterally Loaded single Pile model in Unsaturated Cohesionless Soil

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Abstract. In the past decades, great efforts were spent to understand the behavior of laterally loaded piles in unsaturated soil. The main property of unsaturated soil is the ability to store and release water and introduce capillary zone which increase the soil resistance. Since the unsaturated soil above the water level is governed by two independent stresses, net normal stress ($\sigma - u_a$) and matric suction ($u_a - u_w$). This property is represented by soil water characteristic curve (SWCC), which represented graphically for mathematical relationship between suction and water content. In this work, an attempt is made to investigate the effect of unsaturated sandy soil on the laterally loaded model pile of 16 mm in diameter and 600 mm in length. The pile tested in different saturation conditions (dry, saturated and unsaturated). Lateral loads were applied to the pile head by static lateral load set up arrangement until reach the ultimate lateral capacity. The results shows that decreases in lateral displacement and bending moments resisted by the pile when the soil is unsaturated more than that of dry and saturated conditions for the same relative density and this decrement occurred because of the presence of suction effect in the unsaturated soil.

Key words: Lateral loading, unsaturated soil, Bending moments and Displacement.

1. Introduction.

Natural soils in unsaturated state are common in an arid or semi-arid areas where the ground water level existing below the soil surface in many meters [1]. According to Felix H. Kim et.al., 2012 [2] the mechanical behavior of partially saturated sandy soil is largely affected by the nature of pore water, pore air, and wetting interfaces with soil particle contacts. N. Amoah et.al. 2018 [3] investigations show that in unsaturated soils of low AEV (Air Entry Value) and also in low rainfall areas with high evaporation, large matric suctions developed. H. M. B. Al-Hashemi 2018 [4] noted that the matric suction is dramatically affected by the pore size distribution within a soil sample. Estimating the SWCC (Soil Water Characteristic Curves) allows utilizing and considering the effect of the matric suction in the design of foundations regarding bearing capacity and immediate settlement. It is well-known that because of negative capillary pore pressure, an assemblage of partially saturated sand particles can gain additional shear strength and stiffness, or modify the flow properties and mixing behavior of granular materials [2]. Tariq B. Hamid and Gerald A. Miller 2009 [5], explain that the interfaces of unsaturated soil when in contact with structures such as foundations, retaining walls, and buried pipes. The interface of unsaturated soil with structures can be defined as a layer of unsaturated soil through which stresses are transferred from soil to structure and vice versa. For interface with



unsaturated cohesionless soils the angle of friction with respect to matric suction was greatest for the soil, followed by those for the rough and smooth interfaces.

A1 Mandeel, MAY 2000 [6], stated that deep foundations are used for transferring heavy load structures, such as high buildings, bridges or where soft soils exist near the ground surface. As an application for the advantages of matric suction is the increments of soil resistance to lateral loads applied from these structures to the its supported piles. Fleming et. al 2010 [7] shows that when applied lateral loading on the piles, the pile behave as transversely loaded beams and transfer the lateral load to the surrounding soil mass by using lateral resistance of soil. A. R. Prakash and K. N. Muthukkumaran 2018 [8] noted that for the pile load carrying capacity, the increment in loading rate has a significant influence in load carrying capacity of the pile and this is occur due to the stiffness relaxation of the soil around the pile. The lateral load resistance of pile foundations is strictly important in the design of structures under loading comes from earthquakes, soil movement, waves, piles used in marine structure such as in quay and harbor structures, water forces, ship impact, surge, swing and sway of ship, ship mooring, ice thrust, force acting railway on bridge, soil flow, High rise building, and tower due to wind. The lateral loading corresponding to these structures applied to the pile elements cause to fail or the maximum nodal bending moment or shear force exceeds the limiting values, whichever is less, is considered to be the ultimate lateral capacity [10].

2. Methodology

2.1. Testing Program

The soil used in this study is fine sandy soil, it's particle size distribution curve shown in figure 1. The unit weight of the soil, $\gamma = 15.54 \text{ kN/m}^3$ for medium relative density and the angle of internal friction was, $\phi = 38^\circ$.

The pile model used in this study is aluminum pile of (16mm) diameter and (600mm) length. Steel container of (600mm) diameter and (600mm) depth with four valves fixed at different levels for partially saturation was used to conduct all the tests, the pile model imbedded (500mm) within the soil. The unsaturated condition in this study was obtained by supplying water to the soil in the container from the lower valve as shown in the sketch of Figure 2 until the soil being fully saturated for 24 hours, after that using the other valves for different lowering of water table to a specific level and waiting for 24 hrs. to obtain unsaturated conditions with different matric suction values.

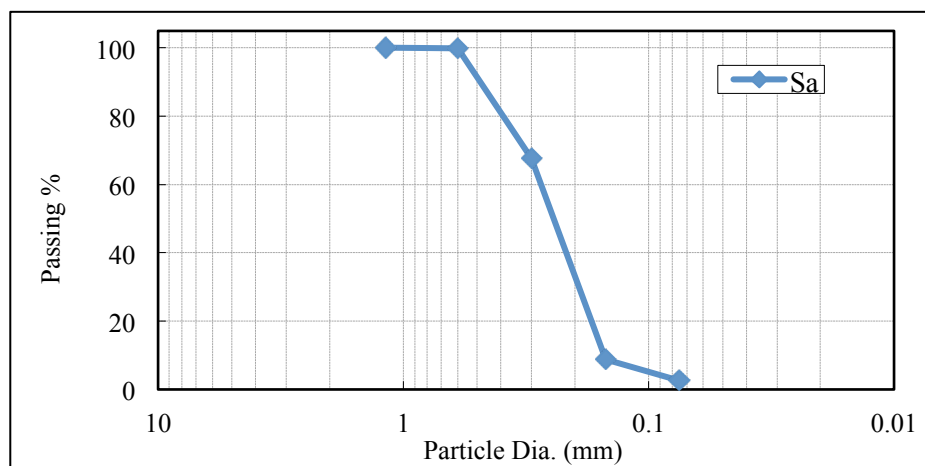


Figure 1. Particle size distribution of the soil used

The pile model is instrumented so, that the displacement of the pile head and bending moments developed along the piles can be measured by using five pairs of strain gages (9mm) size placed at equal spacing of (10 cm) on both sides to measure the compression and tension along the pile length as shown in Figure 2.

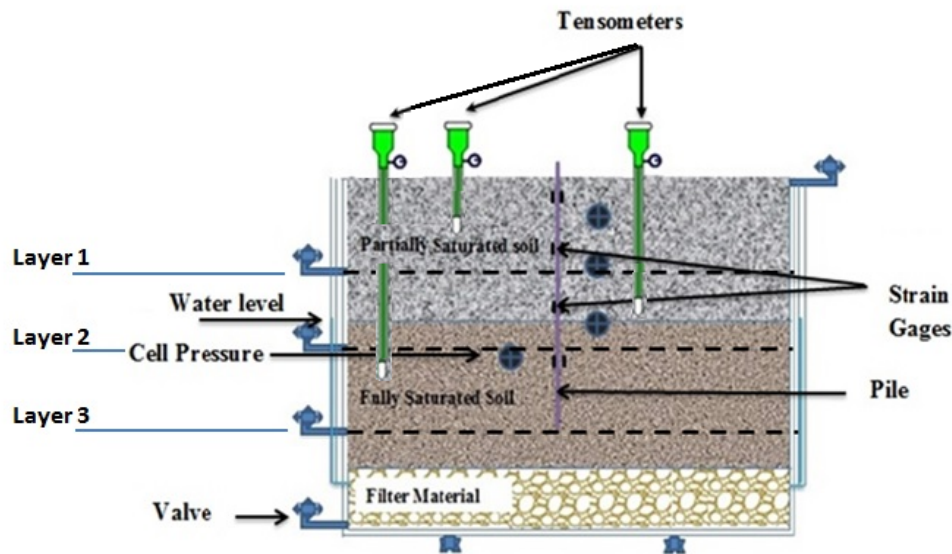


Figure 2. Sketch of testing arrangement shows the location of Tensometer and strain gauges on pile model

Displacement of pile head was measured by using LVDT placed at the head of the pile and connected to LVDT logger to measure the lateral displacement during the test.

Short-term lateral monotonic loading of (20, 40, 60, 80, 100, 120 N) was applied to a pile model which is called static lateral loading. The lateral load was applied through a pulley with a high tension wire joined to the pile head at the soil surface by a loading collar and the other end was attached to the loading plate. Vertical load equal to the allowable pile capacity was applied on the top of the pile model. The static loads were applied to the pile at different soil saturation (dry, saturated and unsaturated conditions) as shown in plate1.



Plate 1. Model preparation for static test

2.2. Soil–Water Characteristic Curve (SWCC) of Partially Saturated Soil

The soil water characteristics curve (SWCC) defines the relationship between the suction of the soil and the water content or degree of saturation of the soil and widely used to estimate unsaturated soil properties [10]. There are several methods for evaluate the soil-water characteristic curve and these methods are divided into two general branches: laboratory and estimating methods. The purpose for evaluate Soil-Water Characteristic Curve is to understand the different behavior of unsaturated or partially saturated soil in terms of strength, stiffness, serviceability, etc.

For this research the soil-water characteristic curve is evaluated in laboratory which is measured directly by a LT Tensiometer (Low Tension) suction device that used for sandy soil as shown in plate (2). The Soil-Water Characteristic Curve shown in Fig.3 [11] represents the suction of the soil used in this research, in order to obtain the Soil-Water Characteristic Curve; the matric suction of soil should be measured, against the gravitational water content.



Plate 2. Soil suction measurement by LT Tensiometer

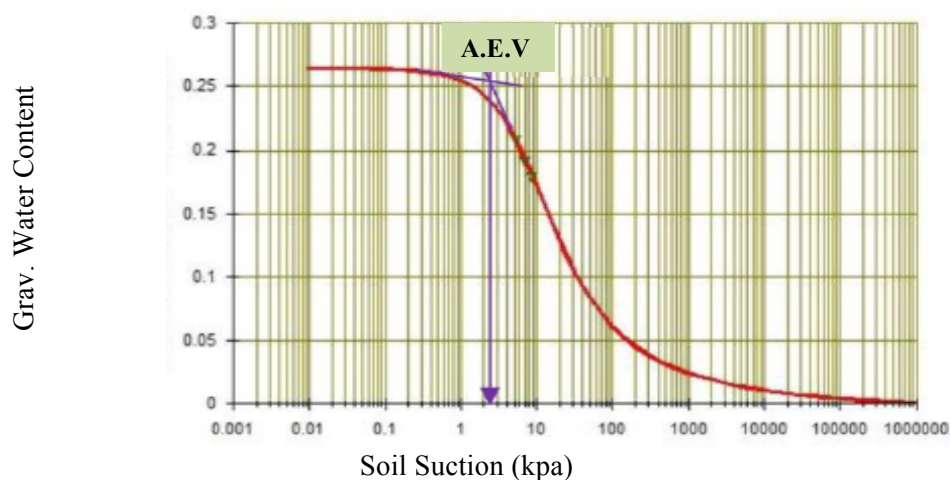


Figure3. Relationships between the gravitational water content and the matric suction obtained by the program Soil Vision by using Fredlund and Xing equation After (M.R. Mahmood 2018)[11].

3. Results and Discussion

3.1. Effect of saturation condition on pile lateral resistance

Figure 4 shows lateral displacement of the pile head at the soil surface with different saturation conditions. The figure shows that the large displacement occurs for fully saturated condition then at dry condition, while for partially saturated conditions a decrease of lateral displacement occurred with the increase of partially saturated zones due to the increases of matric suctions.

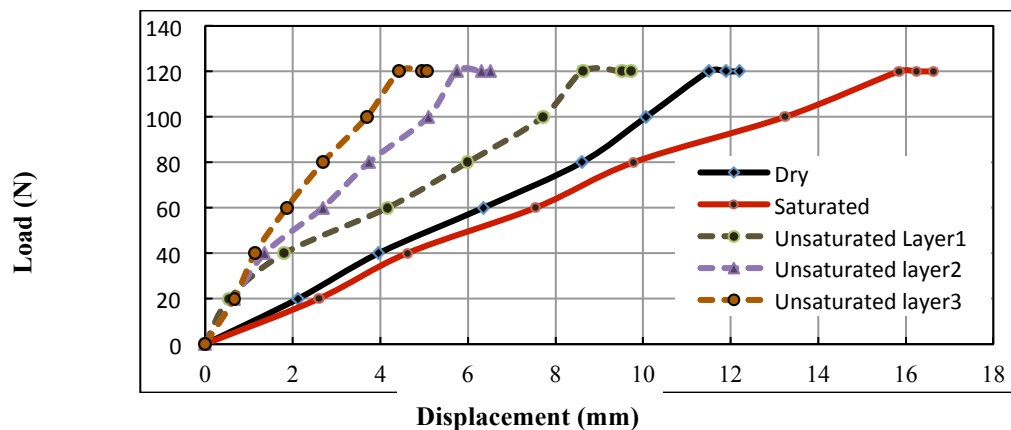


Figure 4. Variation of Lateral Load with lateral Displacement at different saturation conditions

3.2. Effect of saturation condition on pile resistance to bending moments

When the pile tested at dry, saturated and unsaturated conditions there is an observed difference in the bending moment values obtained for each condition. The behavior and results of bending moments when pile subjected to short term lateral static loading (20, 40, 60, 80, 100, 120 N) is shown in figures (5,6,7,8,9 and10) respectively.

The figures show that bending moment applied to the pile due to lateral loads decrease with increasing capillary zone.

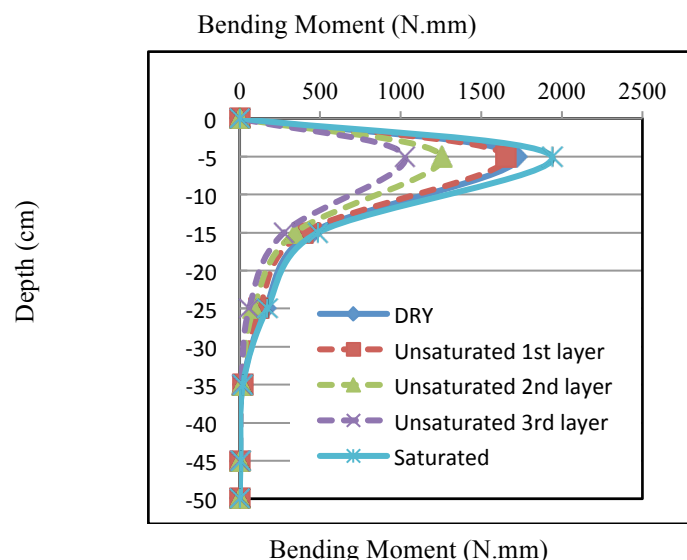


Figure 5. Bending moment for single pile under (20 N) static lateral loading in dry, saturated and unsaturated soil

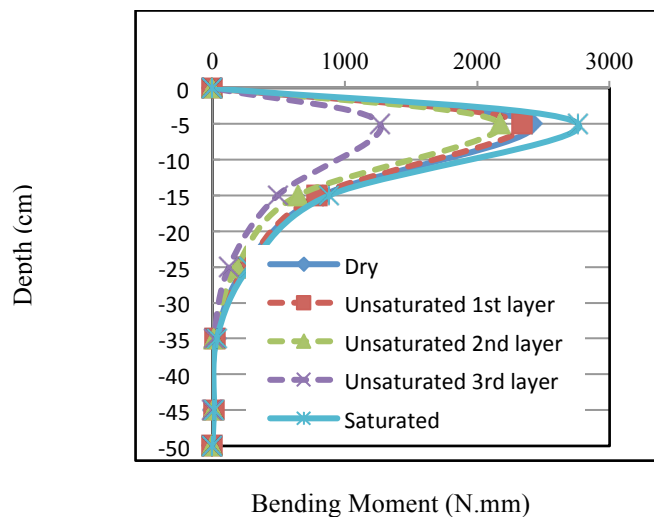


Figure 6. Bending moment for single pile under (40 N) static lateral loading in dry, saturated and unsaturated soil

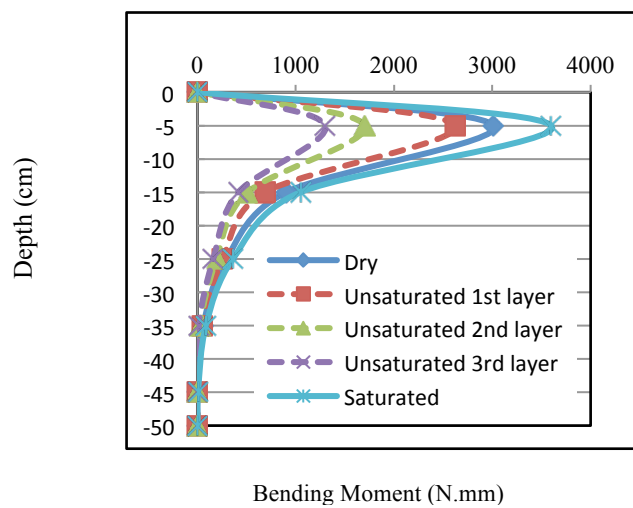


Figure 7. Bending moment for single pile under (60 N) static lateral loading in dry, saturated and unsaturated soil

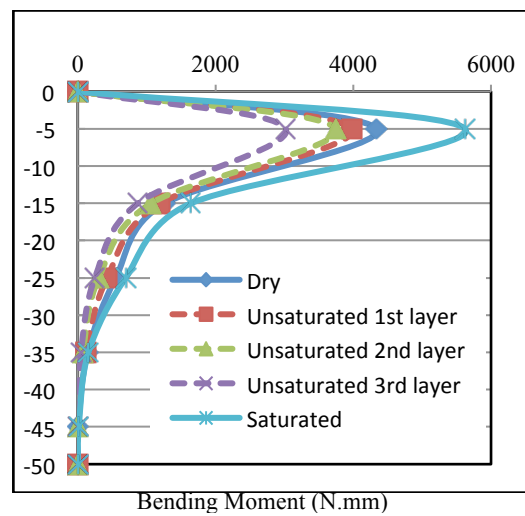


Figure 8. Bending moment for single pile under (80 N) static lateral loading in dry, saturated and unsaturated soil

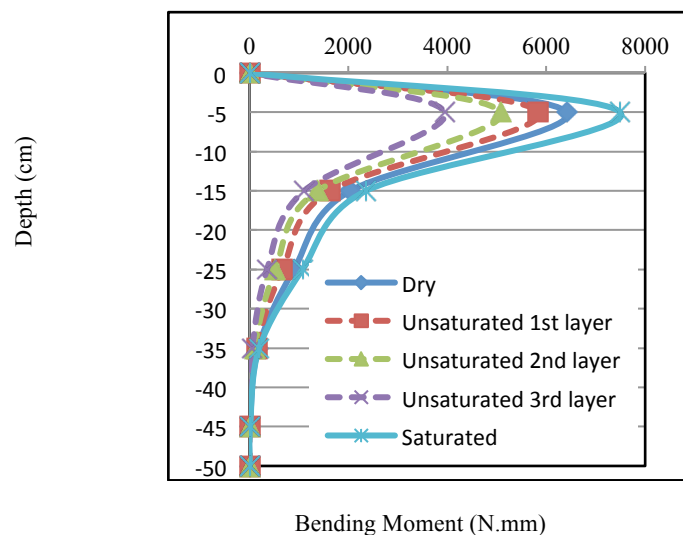


Figure 9. Bending moment for single pile under (100 N) static lateral loading in dry, saturated and unsaturated soil

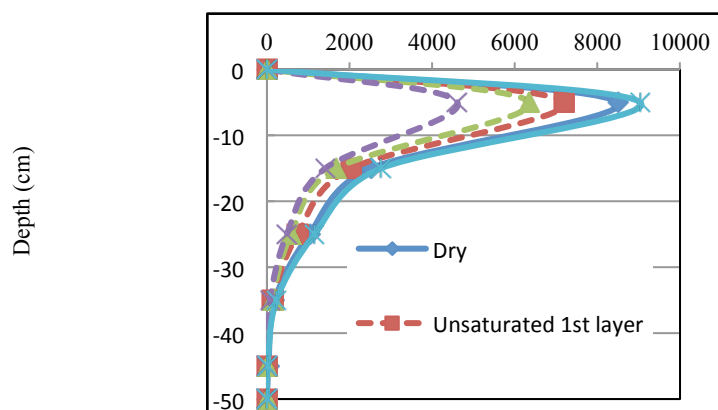


Figure 10. Bending moment for single pile under (120 N) static lateral loading in dry, saturated and unsaturated soil

The degree of saturation has a significantly effect on the behavior of the soil which show higher resistance to lateral loading as the suction of the soil increase because of the increase in the stiffness of the soil and effective stress and this will result decrease in the bending moment as the suction increase as shown in Figure 15.

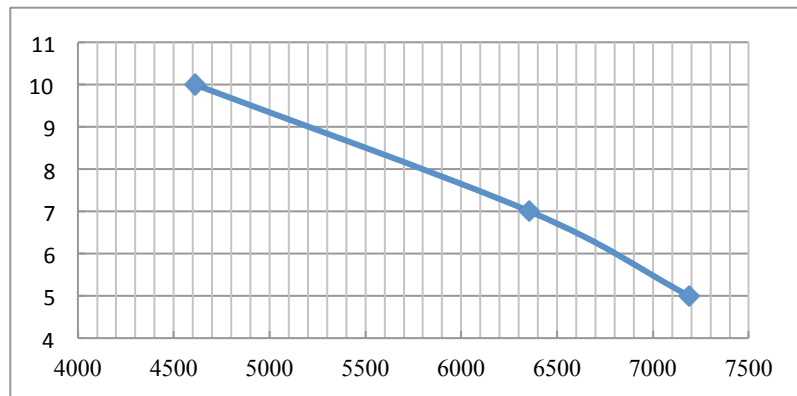


Figure 11. Effect of suction on the bending moment for (120 N) lateral load

4. Conclusions

- A significance of suction zone (of negative pore water pressures) developed in soil has been recognized when lowering water table below the soil surface. The matric suction of this zone increase with increasing the lowering of water table.
- Duo to lowering of water table and create a negative pore water pressure the effective stress and stiffness of the soil increased.
- The lateral displacement of laterally loaded pile in unsaturated soil condition gives the least value compared to the dry and fully saturated condition.
- The resisting to bending moments in the pile under short term static lateral load in unsaturated soil higher than that in dry and fully unsaturated soil. So, the bending moments of laterally loaded pile in the unsaturated soil condition lower than that of dry and fully saturated soils.

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