# Investigation of the Distribution of Skin Friction on Single Pile Constructed In Natural Soft Clay Soil Treated With Stone Columns

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***Abstract* - When any pile is constructed in a soft clay soil may experience dragload and down drag due to the negative friction acting along the pile shaft. In addition soft soil may settle more than the pile, thus generating a negative skin friction along the pile shaft. This negative friction induces additional axial compressive load to the pile dragload and this force pulls the pile further downward. On the other hand Consolidation and settlement of soft clay deposit's surrounding the pile are usually drag the pile downward and it causes a down drag movement to the shaft of the pile. The down- drag movement induces additional loads to the actual loaded pile. This force is expressed as negative skin friction. In this study the distribution of skin friction on single pile during consolidation of soft clay and soft clay stabilized with stone columns have the same diameter and material were studied in the laboratory. The pile is covered with sand paper and it's ended either in soft clay soil, or sand, or soft soil treated with stone columns, whereas, the soft clay layers were allowed to consolidate under the uniform surcharge load equals to 10KN/m$^2$. This study showed that the relative movement between the pile and surrounding soil produces shear stress along the pile shaft and the surrounding soil. In addition to, the neutral plane is depending on stiffness of the bearing soil at pile toe. The stone columns increase the load capacity of the pile and reduce the settlement of the soft clay soils.***

***Keywords* - Pile foundation, negative skin friction, Neutral plane, consolidation, soft soils, settlement rate, stone column**

## I. INTRODUCTION

Soft clay soil is one of the problematic soils which imply low shear strength and high compressibility. Therefore, construction on soft soil is considered a risk. On the other hand, a pile transfers the load from the superstructure to the underlying supporting ground soils through two load-transfer mechanisms: skin friction and end bearing. Skin friction can only be mobilized when relative displacement occurs between the pile and surrounding soft soils. In general situations, a pile subject to a vertical compressive load moves downward with respect to the surround soils. It mobilizes a so-called "positive skin friction" along the pile shaft that helps to hold the pile against the applied load acting at the pile head. However, when a pile is embedded in a consolidating ground as, soft clay soil large ground settlement may occur due to soil consolidation, which would reverse behavior of the soil-pile movement. Adjacent soft clay soils may settle more than the pile, which results in a "negative skin friction" Negative skin friction pulls the pile further downward. This additional drag force is called the dragload, and the associated downward pile head movement is referred to as the downdrag, Fellenius [1].For non-end bearing piles, there exists a location along the shaft where zero relative movement between the pile and the adjacent soils occurs. It is denoted as the neutral plane by geotechnical engineers. It is also the location where the summation of the pile head load and the dragload equals the resistance provided by the positive skin friction and the end bearing resistance of the pile.

An excessive amount of dragload may cause the pile's structural strength to be exceeded. The trouble becomes especially important for long piles where the dragload due to the accumulation of negative skin friction could be extremely large. This force is the most common problem in the designed and construction of pile in soft clay soils, Sangseom [2].

(Acar et al. [3] and Poulos [4] noted that the magnitude of dragload and downdrag are dependent on the origin of negative skin friction when ground consolidation. Over several decades, many sites monitoring record demonstrated the phenomenon of negative skin in precast piles driven through soft clay and silty sand strata (Endo et al. [5]; Bozozuk [6-7],; Fellenius[8]; Walker and Darvall [9]; Lee and Lumb[10]; Fukuya et al. [11]; Leung et al. [12]; Indararatna et al. [13]; W. M. Yan, M.ASCE1; T. K. Sun2; and L. G. Tham, M.ASCE3. [14]; EL-Sahkhawy N,and Nassar A [15].

Stone column technique is the one of the most commonly used soil improvement technique for soft clay soils. The technique has been used to increase the load carrying capacity of soft soils and to reduce the settlement of superstructure constructed on them. The theory of load transfer, estimation of ultimate bearing capacity and prediction of settlement of stone columns were proposed by Greenwood [16], Vesic [17], Hughes and Withers [18] and later by Priebe [19], Datye and Nagaraju [20] proved that the stone columns reduced the settlement significantly. Recently, Kumar and jain [21] and Kumar [22] show that the technique of improving the soft soils by stone columns can also be used in soft expansive black cotton soil.

This study is focused on the distribution of skin friction on pile constructed in soft clay during soil settlement under surcharge load; a special tank was designed and manufactured to achieve this goal. The setup consists of : piles model, steel model, loading system, strain gauge with strain indicator, stone columns.

## II. EXPERIMENTAL WORK

***Steel Model***

A movable steel Model was designed to host the bed of soft clay soil and all accessories. The circular Model was made of steel plate 3 mm in thickness. The internal dimensions are 520 mm diameter and 750 mm height. These dimensions were chosen to eliminate the boundary effect. The Model was provided with four plates of steel (20*20*5) mm that allows it to move freely and provided with sheet of Perspex (520*50) mm and has a 5 mm thick on the outer surface of the Tank, to see and adjust the height of the soft clay layers. Figure 1, shows details of the Model.

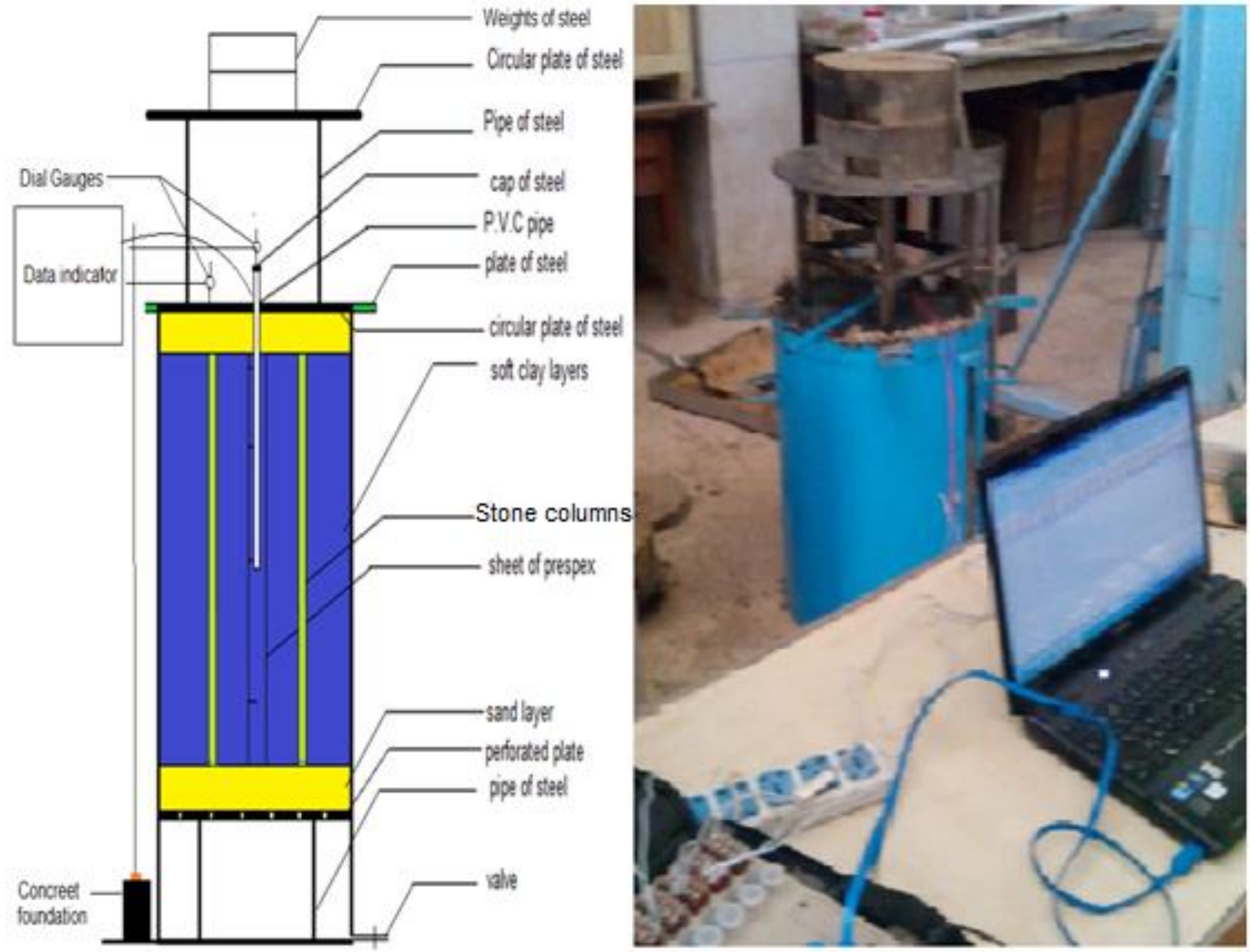


**Figure 1. Experimental Model**

***Used Materials***

**1. Soft Clay**

Soft clay of high plasticity was collected from Tahta city in Sohag- Egypt. The soil was subjected to laboratory tests to determine its properties, these tests include : Atterberg limits (Liquid and plastic limits) and specific gravity according the Egyptian code of soil mechanics and foundations [23]. The results show that the soil is classified as clay of high plasticity (CH). The liquid limit and plasticity index are 65.55percentage and 36.87percentage respectively. The drained shear stress of soft clay is 6 KN/m2 at moisture content of 58.85 percentages.

**2. Crushed Stone**

The size of the crushed stone particles were chosen in accordance with the size guidelines had been suggested by Nayak [24] and Al-Shaikhly [25], where the particle size is about 1/7 to 1/9 from the diameter of stone columns opening. The particle sizes of stone chips varying from 3mm to 5mm. The results show that the stone chips are classified as poorly graded.

**2.3 Pile Model**

Three P.V.C circular model pile with different diameters of 16, 26 and 32 mm were chosen to model the pile in this investigation. On the other hand, compression tests were carried out on three specimens of this P.V.C pipes to determine its modulus of elasticity. The modulus of elasticity of the pile material is 12*105 KN/m2.The surface of the pile is covered with sand paper. Pile alignment device was designed to hold the model pile in position through the holes in upper plate. The pile model was covered at its top by a circular cap of steel to mount the dial gauge on it.

### 2.4 Installation of Stone Columns

The position of the stone columns was suggested at distance equal to three times of the pile diameter. A hollow P.V.C pipe with external diameter of 32mm coated with petroleum jelly was pushed down through the soft soil. The stone columns were studied in the end bearing case. Figure 2 shows installations of the stone columns surround the pile. To remove the soil inside the P.V.C pipe, a hand auger, manufactured for this purpose was used. After that, the P.V.C pipe was removed carefully while the crushed stone were gradually charged into the hole in five layers and each layer compacted by using 20mm diameter rod of steel. Spacing between stone columns was chosen to be 65mm as shown in Figure 2.

**Figure 2. Installation of stone columns**

## III. MODEL TESTING PROCEDURE

The model tests were carried out on natural soft clay and soft clay improved with ordinary stone columns. The tank, the top disk and lower perforated disk are cleaned and polished with petroleum jelly to reduce soil adhesion during test. The P.V.C pile model is provided with strain gauges and lowered vertically in the tank before the placement of soft clay soil. After that soft clay soils are statically compacted on layers of about 100 mm were laid on the tank. Then, four stone columns have diameter 32 mm are constructed at distance equal to three times of the diameter of the P.V.C pile. The sand layer is placed over the soft clay soil to allow upper drainage during consolidation, and then the circular plate of steel placed over the soil to distribute the pressure from load to the soil uniformly and compact the soil deposits. One dial gauge with accuracy of (0.001mm/division) was fixed in position to measure the settlement of the upper circular disk due to soil settlement, and another dial gauge was placed in the top of the P.V.C pile to measure the settlement of the pile during consolidation of the soft clay. Then, the wiring of the strain gauges was connected to the data indicators as shown in Figure 3.

**Figure 3.Dial gauges and the arrangement for surcharge load**

### 3.1 The Experimental program

Table (1) illustrates the experimental program. In the present study three cases were studied. The first case is the pile ended in the soft clay layer. The second case is the pile ended in the dense sand layer, and the third case is the pile embedded in soft clay was improved by stone column.

**Table (1) Different cases and their indicated codes**

| Test NO | CASES | Pile Diameter (mm) | L/d | Pile length (mm) | Clay Thickness (mm) | Lower sand Thickness (mm) | Code | No Of strain gauges |
|---|---|---|---|---|---|---|---|---|
| 1 | Case I | 16 | 10 | 160 | 350 | 50 | L160EC | 3 |
| 2 | | | 15 | 240 | 350 | 50 | L240EC | 3 |
| 3 | | | 20 | 320 | 400 | 50 | L320EC | 4 |
| 4 | | 26 | 10 | 260 | 350 | 50 | L260EC | 3 |
| 5 | | | 15 | 390 | 400 | 50 | L390EC | 4 |
| 6 | | | 20 | 520 | 600 | 50 | L520EC | 4 |
| 7 | | 31 | 10 | 310 | 350 | 50 | L310EC | 4 |
| 8 | | | 15 | 465 | 595 | 50 | L465EC | 4 |
| 9 | | | 20 | 620 | 650 | 50 | L620EC | 4 |
| 10 | Case II | 16 | 10 | 160 | 160 | 240 | L160ES | 3 |
| 11 | | | 15 | 240 | 240 | 160 | L240ES | 3 |
| 12 | | | 20 | 320 | 320 | 80 | L320ES | 4 |
| 13 | | 26 | 10 | 260 | 260 | 140 | L260ES | 3 |
| 14 | | | 15 | 390 | 390 | 60 | L390ES | 4 |
| 15 | | | 20 | 520 | 520 | 130 | L520ES | 4 |
| 16 | | 31 | 10 | 310 | 310 | 90 | L310ES | 4 |
| 17 | | | 15 | 465 | 465 | 240 | L465ES | 4 |
| 18 | Case III | 16 | 10 | 160 | 160 | 240 | L160SC | 3 |
| 19 | | | 15 | 240 | 240 | 160 | L240SC | 3 |
| 20 | | 26 | 10 | 260 | 260 | 140 | L260SC | 3 |
| 21 | | | 15 | 390 | 390 | 60 | L390SC | 4 |

## IV. ANALYSIS OF RESULTS AND DISCUSSIONS

In the following sections, the results obtained from experimental tests are presented and discussed. The conducted tests consist of 21 tests. Three cases of tests for three values of (L/d) ratio (L/d=10, 15, and 20) were performed. Each case includes three tests for pile diameters (D = 16mm, 26mm, and 31mm).The monitored date were analyzed to study the behavior of piles in soft clay soil.

### 4.1 Time - Strain Behavior of Pile.

### 4.1.1 The pile ended on Soft Clay Soil

Figure 4 shows the axial strain with time of applying the surcharge load, for pile model (L520Ec). The pile has 520mm pile length and 26mm diameter and has length to diameter ratio equal to 20 ending in the soft clay bed. It can be noted that the strain occurred at the top location is higher and took place with rate earlier than both of, lower middle, and bottom. However, it's decreased after reaching the maximum value. Whereas, the others strain were continuing increasing with similar rate until the end.

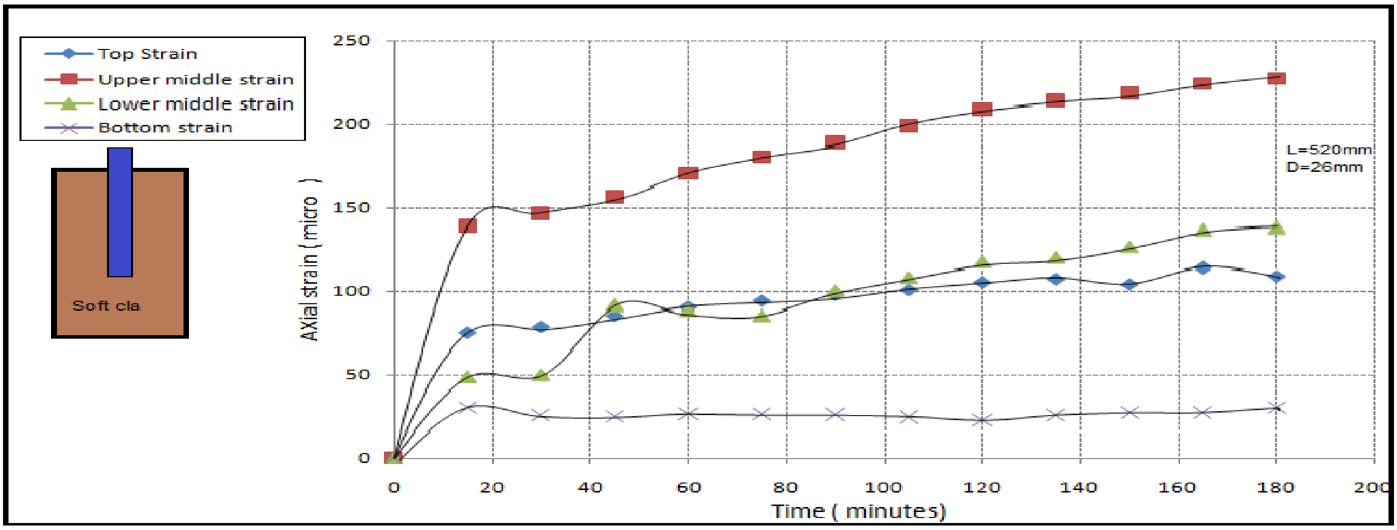


**Figure 4. Time – Axial strain curves of pile model (L520EC)**

It is clear that consolidation took place at the top portion of the soft clay due to the nearby from the surcharge load with rate faster than the remaining layers. This is due to the water path to dissipate is shorter at the near surface than at other locations. For the time being, the rate of excess pore water dissipation decreases, then the axial strain decreases. The strains were occurred in upper middle locations continue increasing with rate higher than the lower middle strain. This can be attributed to increased overburden pressure with depth. In addition to, the water path for dissipation is shorter than the lower middle strain.
The strain was occurred in the bottom location is more less than the top, upper middle, and lower middle strains, because the consolidation process at the bottom portion of soft clay layer will need a long time until occurs. This is due to the distance that pore water move out from the certain depth is longer compared with top, upper middle, and lower middle strains.

### 4.1.2 Time - Strain Behavior of Pile Model ended in Sand

Figure 5.shows the pile strains for pile model (L520ES). The pile is for 26mm diameter and 520mm embedded length in soft clay deposits. It can be noted that the bottom strain generally large when compared with the pervious case of piles ended in the soft clay soil. This can be attributed to the increased rate dissipation of excess pore water pressure through the bottom portion. In addition to, sand layer resists the pile movement, leads to increasing stress in the bottom portion of the pile, so it's caused increase in the monitored strain with 225 percentages.

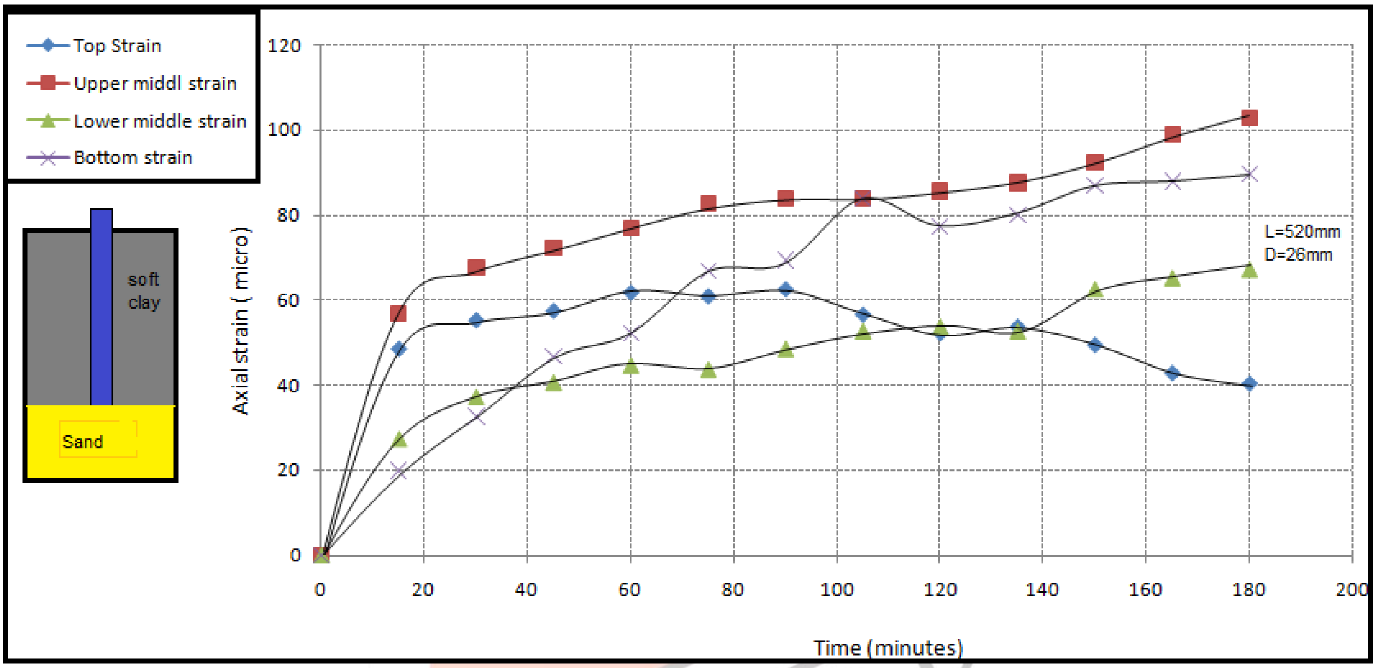


**Figure 5 Time- Axial strain curves of pile model (L520ES)**

### 4.1.3 Effect of Stone Columns on Time- Strain curves of pile

Figures 6 shows the axial strain with time of applying the surcharge load, for pile model (L160EC), has16mm diameter and 160mm embedded length in untreated soft clay deposits. That is, the pile length to diameter ratio is equal to 10. While Figure 7 shows the axial strain with time of applying the surcharge load, for pile model (L160CS). The pile has 16mm diameter and 160mm embedded length in soft clay deposits treated by four stone columns has 32mm diameter and160mm length. The strain values were obtained of soft clay, and soft clay treated by stone columns were plotted and tabulated in Table 2.

**Table (2). Strains values of pile treated by stone columns**

| Case | Strains (micro) | | |
|---|---|---|---|
| | Top strains | Middle strains | Bottom strains |
| Untreated soft clay | 69.525 | 36.368 | 15.363 |
| Treated soft clay | 31.464 | 31.416 | 13.232 |

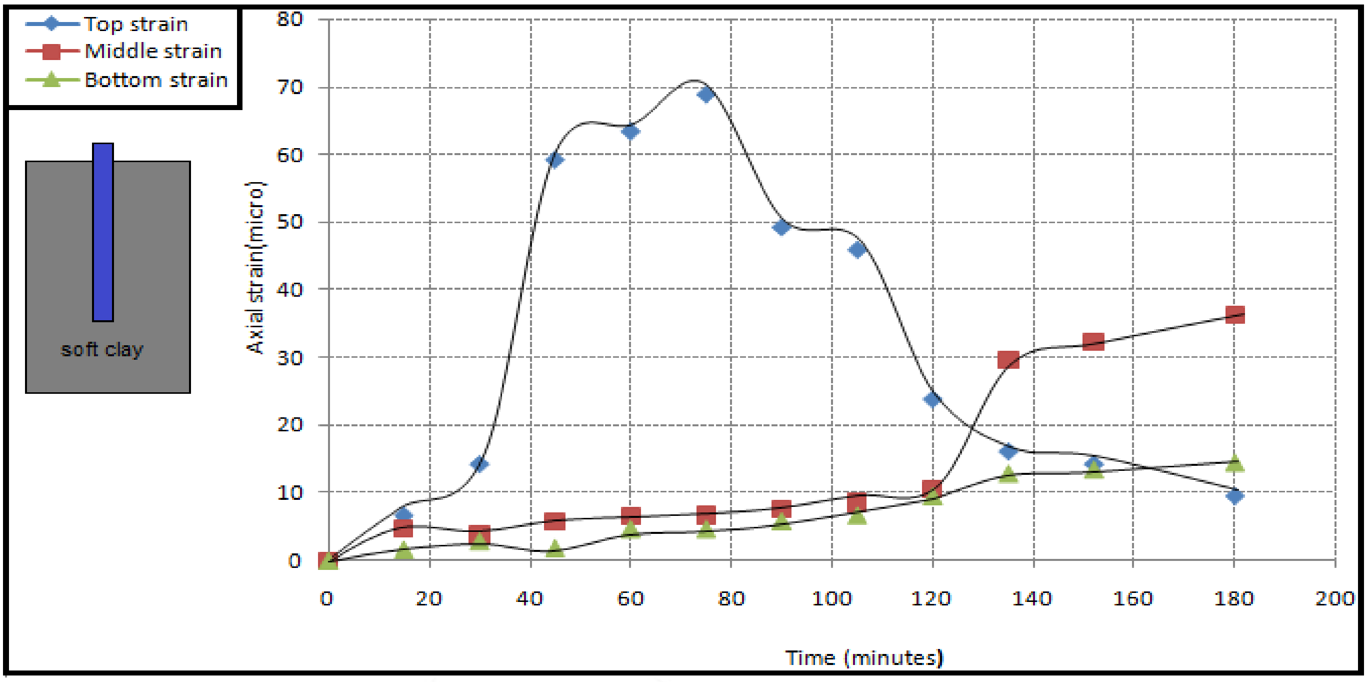


**Figure 6 .Time- axial strain curves of pile model (L160EC)**

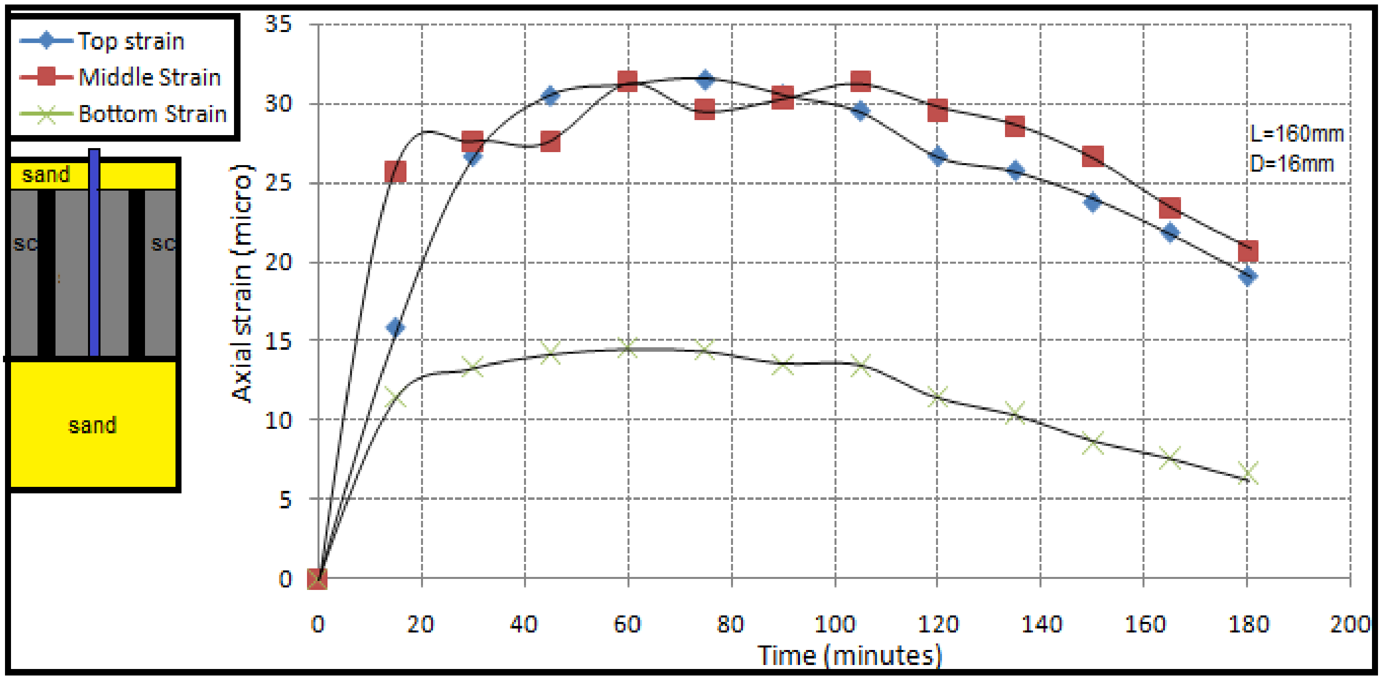


**Figure 7. Time- axial strain curves of pile model (L160SC)**

The comparison between pile models (L160EC) and (L160SC) were done, and it's indicated that the important role of stone column to accelerate the consolidation process of soft clay. Figure 7 indicated that the complete consolidation of soft clay layers treated with stone columns was achieved at much shorter period of time than the natural soft clay soils. This may be attributed to stone column plays two influential roles in the soft clay soil, firstly, as a part of soil, it improve the settlement behavior of the soft clay soil, Secondly, stone column acts as a vertical sand drains and thus speeding up the process of consolidation. Hence, the top, middle, and bottom strains are generally small when compared with the pile ended in natural soft clay soil.

**4.2 Distribution of normal strain along depth of the pile.**

Figure 8 describes the distribution of normal strain along the depth of the pile. The exhibit strains are those observed at the end of the test for pile model has a 16 mm diameter and 240 mm length embedded in the soft clay deposits. Three cases are considered in the figure; piles ended in soft clay, pile ended in sand, and pile embedded in soft clay treated by stone columns and ended in sand.

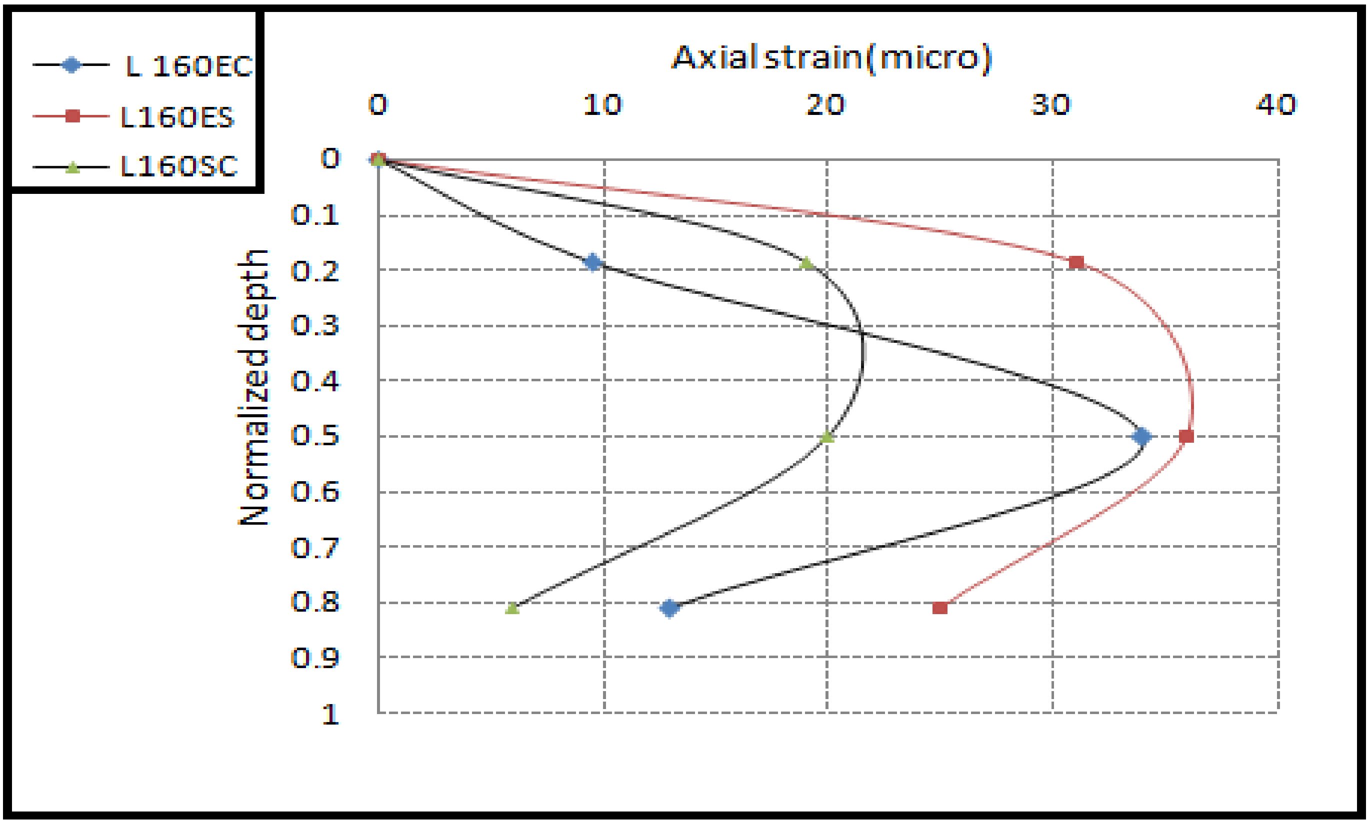


**Figure 8 Axial strain Distribution along pile for cases (L160EC, L160ES, L160SC)**

On the other hand, Figure (8) shows slight values of strain are indicated in the upper part. This can be attributed to the excess water pressure had dissipated, and then consolidation process had decreased. Also this Figure indicates that the axial strains increase until it reaches a maximum value, then it decreases. Strain decrease mirrors decrease in the negative skin friction (dragging force).This can be attributed to the side resistance of pile reverses for negative skin friction to positive skin friction. It is also the location of the maximum strain in the pile and where there is no relative movement between the pile and surrounding soft clay soil. On the other hand, it can be seen from this Figure, the axial strain increases in case of pile ended in sand more than pile ended in soft clay deposits. Then the peak point of strain in case of pile ended in soft soil is approached of middle of the pile, while in case of pile ended in sand the peak point is approached of the pile toe, Further more can be seen that the stone column reduced the strains significantly.

**4.3 Relative displacements between the pile and surrounding soil**

The settlement values of pile and soft clay soil for models (L160EC, 160LEC, and 160SC) were monitored from dial gauges during the consolidation process are tabulated in Table 2 and bloated in figure 9.

**Table 2 Relative displacement of pile models (L160EC, 160ES, and 160CS)**

| Case | Settlement(mm) | | Relative displacement (mm) |
|---|---|---|---|
| | Pile | Soil | |
| L160EC | 0.87 | 3.42 | 2.55 |
| L160ES | 0.69 | 3.75 | 3.06 |
| L160SC | 0.008 | 1.87 | 1.862 |

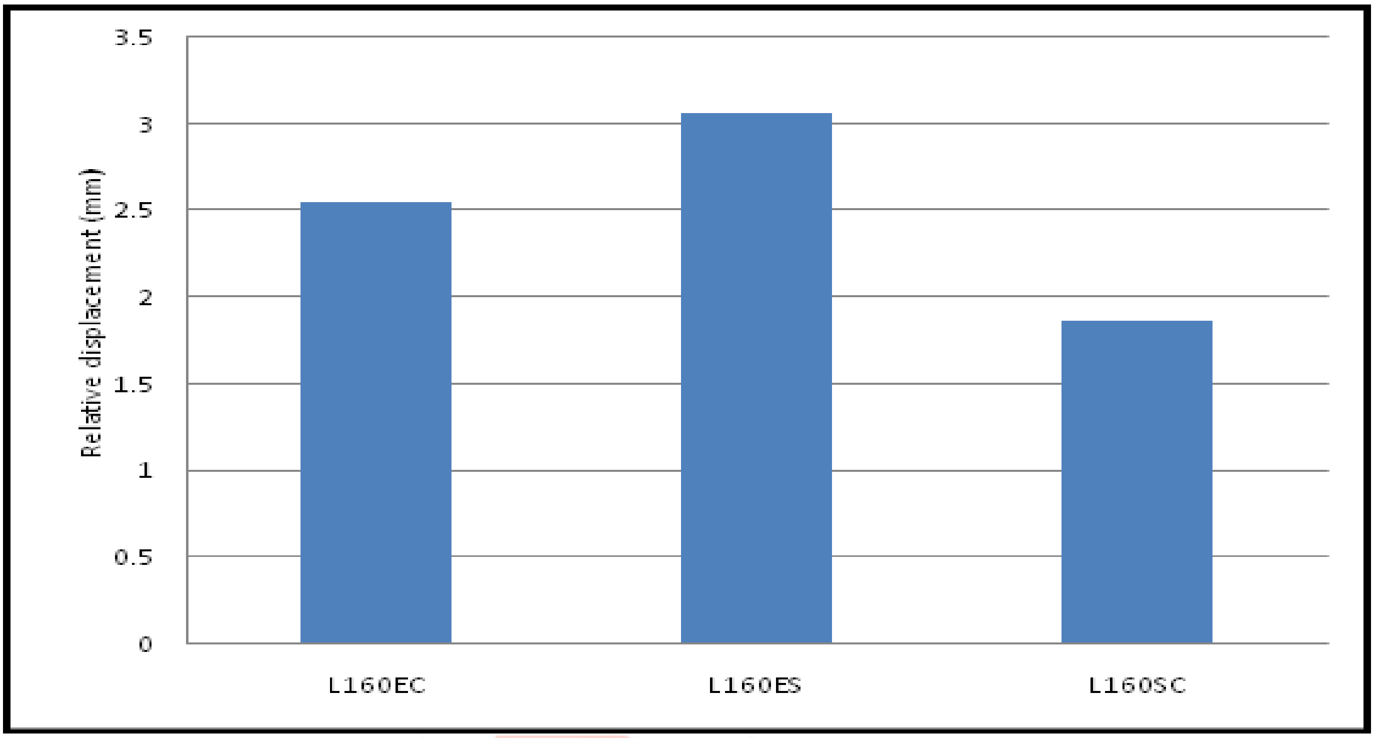


**Figure 9 Relative displacement of pile models (L160EC, L160ES, and 160SC)**

From Table 2 and Figure 9, it can be noted that there is always occurs relative displacement between the surrounding soft soil and the pile. Also, Figure 9 indicated that the relative displacement in case of pile embedded in soft clay soil is smaller than case of pile ended in sand. As well as the stone columns reduces displacement of the surrounding soft clay soils of about 54.68 percentages. On the other hand relative displacement develops negative skin friction on the pile and this adds an additional load to be carried loaded by the pile. Hence, this additional load decreases the ultimate bearing capacity of the pile, whereas, when the pile is in static equilibrium the sustained top plus the cumulative negative skin friction is equal to the cumulative positive side friction plus the toe resistance.

**4.3 Effect of Stone columns on Time- Strain Behavior of Piles during Consolidation of Soft Clay Soils.** Figure 10 represents the developed strains in the pile for two cases of end conditions. The first case (L160ES),
case of pile has 16 mm diameter and 160 mm length ended in sand soil. The second case (L160SC), case of pile has 16 mm diameter and 160 mm length ended in soft clay soil treated by four stone columns has 32 mm diameter and 160 mm length. The shown strains are those monitored from strain gauges were fixed on the middle and bottom locations. From the figure, it can be seen that using the stone columns decreases the developed strain in the soft clay soil. In addition, pile ended in sand received more strains than these embedded in soft clay treated by stone columns. On the other hand, used stone columns decrease the axial strain of the pile, and then it decreases the settlement of soft soil clay soils.

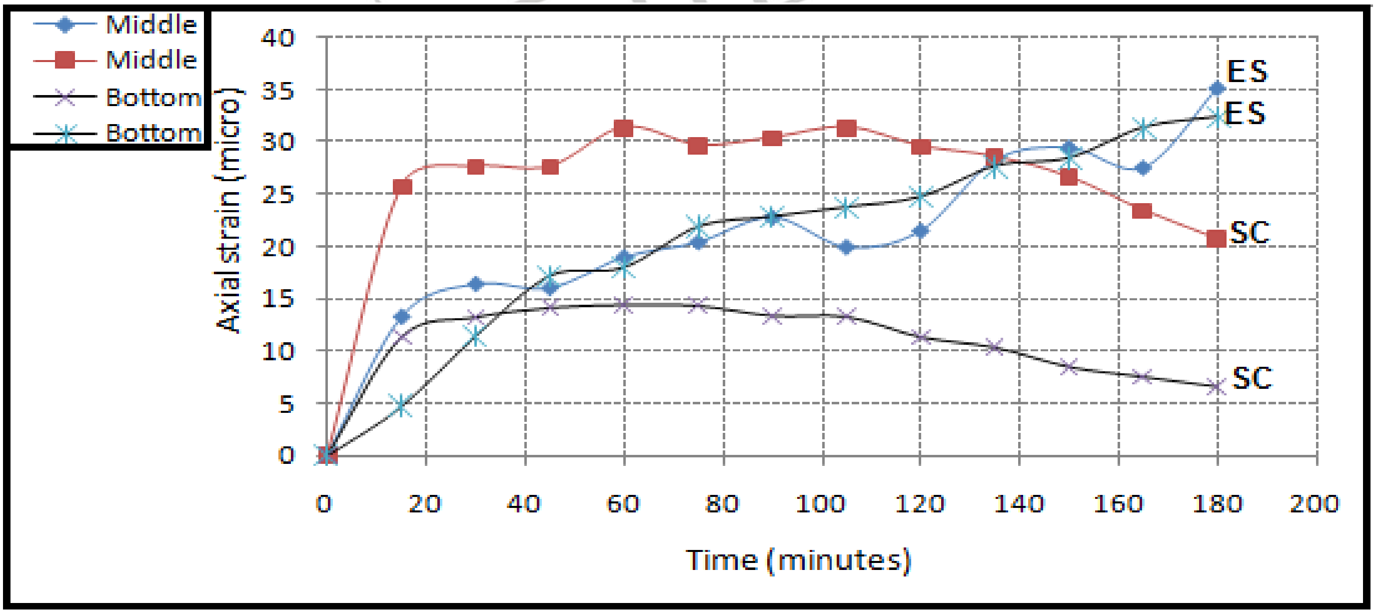


**Figure 10 Time- Axial strain curves of pile models L160ES, and L160SC (Same Strain locations at the Middle and Bottom, pile has 16mm Diameter and160 mm length)**

## V. CONCOLUSION

Based on the presented discussion and analysis the experimental results carried out on twenty one of pile models constructed in both, natural soft clay, and soft clay treated with stone columns. The finding summarized as given below.

- Stone columns accelerate the consolidation process significantly, as the stone column behaves like sand drains.
- Consolidation process of the soft clay deposits surrounding the pile develops negative skin friction on the pile shaft.
- Negative skin fraction adds additional load on the actual load of the pile.
- The distribution of the axial strain along the pile mirrors the dissipation of excess pore water pressure with time.
- Dragging force increases with increasing the friction between the pile and the surrounding soil.
- Magnitude of skin friction increases when the soil at toe of the pile getting stiffer.
- Stone columns play an effective role in reducing the settlement of the soft clay soil.
- Relative displacement between the pile and surrounding soil deduces shear stress along the pile shaft.
- Stone columns reduce the strain occurred in soft clay soils.
- Stone columns play an effective role in increasing the bearing capacity for the soft clay soils, which it leads to increasing the resistance capacity of the pile.
- Both, settlement of soft clay soils and negative skin friction have significant time effect.

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