SHAFT RESISTANCE OF MODEL PILE IN DRY SILT

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ABSTRACT:A test apparatus to measure the load transfer along the shaft of a model pile inserted in a specimen of silt is described.This apparatus allows independent control of the boundary stresses of a cylindrical silt specimen in the vertical and horizontal directions.The load transfer along the shafts of smooth and rough surfaces aluminium model piles in dry silt under static load was measured.The pile installation technique used was designed to minimize soil disturbance so that the failure criterion for pile shaft friction could be investigated.The study shows the importance of the boundary conditions of the soil specimen surrounding the model pile.The study also shows the effectiveness of using rough pile in increasing the pile capacity.The magnitude of pile-displacement at failure which necessary to mobilize the ultimate shaft resistance varies significantly with the surface roughness of the pile.The results show that the angle of the pile-silt contact depends on the roughness of the pile surface, initial density, void ratio and horizontal confining pressure

Keywords –Pile shaft resistance – model pile tests – friction angle - axial load - static loading tests

INTRODUCTION

The computed values of unit shaft resistance for all the tests are plotted as a function of the horizontal confining pressure.The relationship is basically a linear one   which can be expressed as:

$$f_s = \sigma_h \; \tan (\delta) = k \; \sigma_v \; \tan (\delta)$$

where σ_h is the effective normal stress acting around the pile shaft at failure, δ is the angle of friction between the pile and the soil, k is the coefficient of lateral earth pressure and σ_v is the effective vertical stress around the pile shaft.

In this paper the shaft resistance of smooth and rough model piles under static loading in dry Silt is investigated by a pile-soil shaft resistance test apparatus. The influence of the important mechanical parameters is investigated to simulate shear resistance along the pile shaft in different Silt densities. Six tests were carried out on smooth model pile and six tests on rough model pile which were tested in Triaxial apparatus.

Model pile tests have been used to study the load transfer characteristics of piles. The pile-soil shaft resistance test apparatus is shown in figure (1). The test apparatus allows the control of horizontal and vertical pressures on a cylindrical specimen of soil with a circular model pile erected in it. The axial load on the model pile was measured by means of a load cell seated on top of the model pile, while the axial displacement was measured using a dial gage.

EXPERIMENTAL PROGRAM

As shown in   figure (1) the available model tests in the literature were examined. The specimen can be restrained to generate a condition approximately at rest. The bottom surface of the specimen is supported on a rigid base.
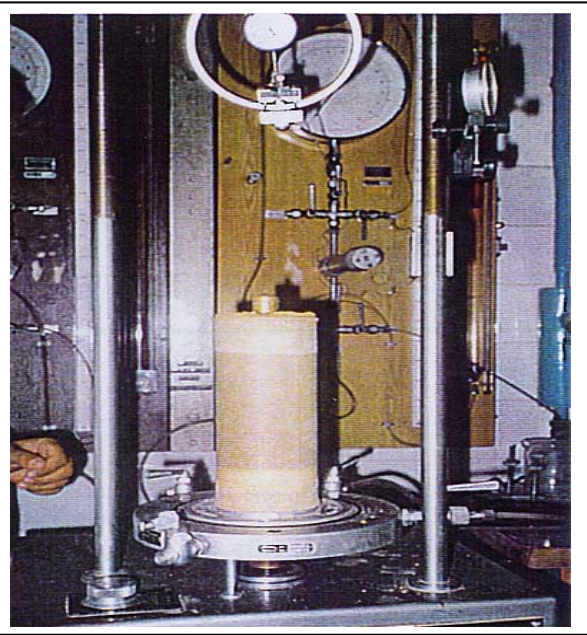
FIG. 1. Test Apparatus

FIG. 2. Specimen of soil

A number of static loading tests were performed at a constant rate of displacement to determine the load capacity of an aluminium model pile (200) mm in length and (26.5) mm in diameter for smooth surface and (27.5) mm for rough surface. Two types of boundary stress and displacement conditions were imposed on the soil element in this study as shown in tables (2) and (3).

The successive tests were achieved by increasing the vertical pressure while preventing the lateral deformation of the soil element before and during the load test. During the test, the specimen was not allowed to expand horizontally. The physical properties of the Silt are shown in the table (1).

Table 1. Physical properties of silt

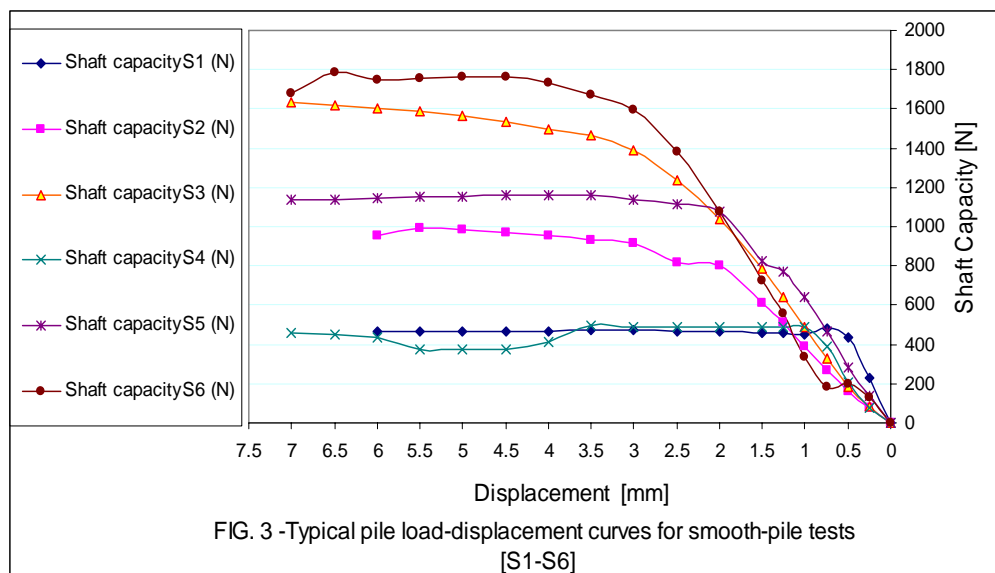| Condition of soil	Specific density gm∕cm^3	Dry density gm∕cm^3	Uniformity coefficient Cu	Void ratio e	Relative density Dr %
Loose dry silt	2.70	1.43	3	1.23	47
Dense dry silt	2.70	1.80	3	0 > 69	68

TEST PROGRAM

The silt specimen, (100) mm in diameter and (200) mm in height, were prepared by pouring the Silt around the pile into a thin acrylic cylinder which was holding a rubber membrane (100) mm in diameter and .(3) mm in thickness as shown in the figure (2).

The Silt was deposited in 5 equal layers and each layer was tamped by a tamper to achieve a relative density of approximately (47 and 68) % for loose and dense dry Silt respectively in all specimens. After preparing the specimen and before applying any confining pressure, the acrylic cylinder was removed, then lateral confining pressure was applied on the rubber membrane encasing the specimen and the vertical pressure was applied on the top of the soil specimen and the test carried out upon constant volume. After preparing each specimen the pile was subjected to a static axial load at a constant rate of displacement. The axial load was applied through a downward movement of the pile relative to the fixed soil element at a constant rate of displacement of (0.5) mm per minute.

Table 2- Summary of loading tests using smooth pile

Soil condition	Test	Initial condition			Ultimate shaft capacity Pu [N]	Failure Displacement Pf (mm)	Pf/L %	Pf/d %
		σh (kpa)	σv (kpa)	K				
Loose dry silt	S1	100	294		470	3.0	1.5	11.3
	S2	200	588	0.34	994	5.5	2.75	20.7
	S3	300	882		1630	7.0	3.5	26.4
Dense dry silt	S4	100	370		499	3.50	1.75	13.2
	S5	200	714	0.28	1162	4.0	2.0	15.1
	S6	300	1071		1789	6.5	3.25	24.5

FIG. 3 -Typical pile load-displacement curves for smooth-pile tests [S1-S6]
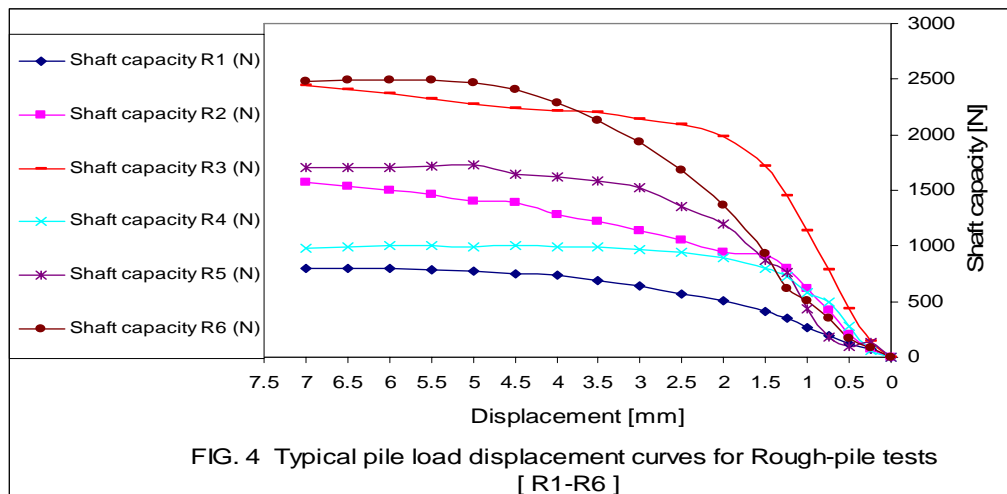
TEST RESULTS

Tables (2) and (3) list the results and conditions of the load tests on the smooth and rough model piles respectively.

Table 3- Summary of loading tests using rough pile

Soil condition	Test	Initial condition			Ultimate shaft capacity Pu [N]	Failure Displacement Pf (mm)	Pf/L %	Pf/d %
		σh (kpa)	σv (kpa)	K				
Loose dry silt	R1	100	294		804	7.0	3.5	25.5
	R2	200	588	0.34	1570	6.0	3.0	21.8
	R3	300	882		2438	6.0	3.0	21.8
Dense dry silt	R4	100	370		1003	4.5	2.25	16.4
	R5	200	714	0.28	1727	5.0	2.5	18.2
	R6	300	1071		2495	6.0	3.0	21.8

FIG. 4 Typical pile load displacement curves for Rough-pile tests [R1-R6]

1-Effect of surface roughness

Surface roughness of the pile has an important effect on the shaft resistance of the pile. The maximum shear stress developed by rough surface piles is higher than that developed by smooth surface piles. Hence, the maximum shear stress means the ultimate shaft capacity Pu , where (end bearing resistance = 0).
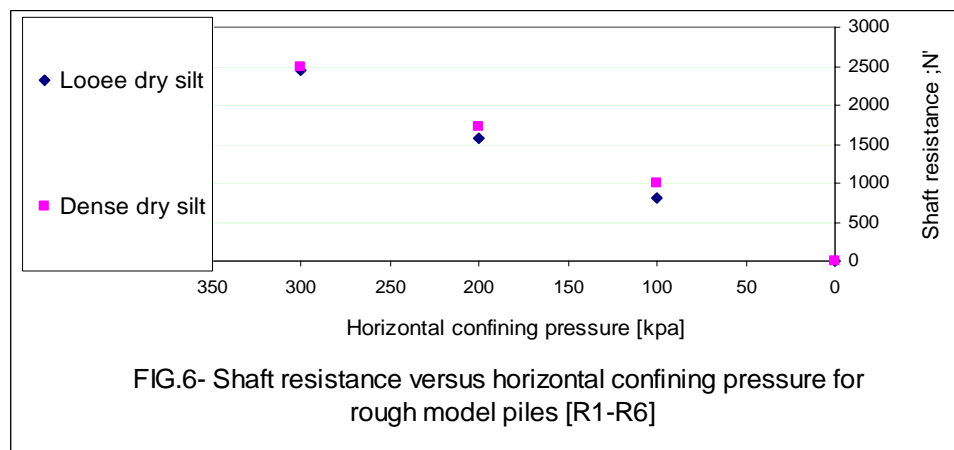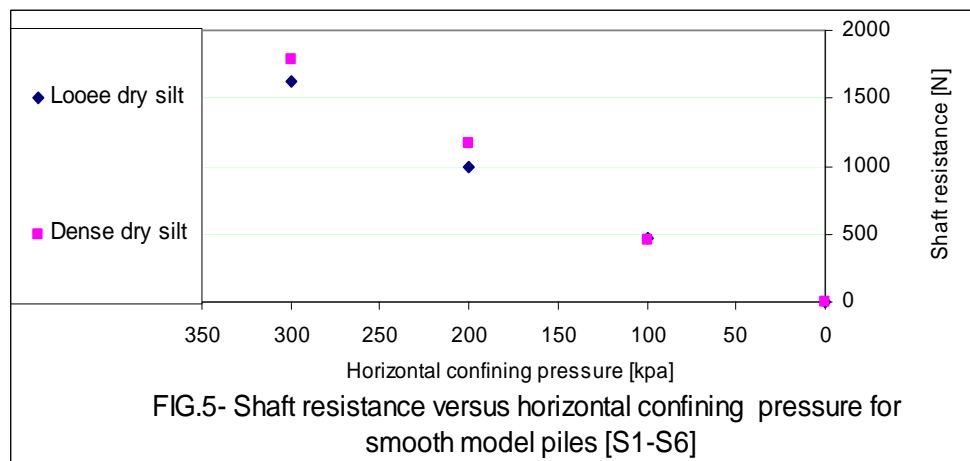
At a relative density of 47 %   for loose dry Silt, the ultimate shaft capacity of the rough piles is in ranges (1.71, 1.58 and 1.50) respectively, times as much as that of smooth piles as shown in tables (2) and (3) for k=0.34 , where it is ranges (2.18, 1.49 and 1.39) times as much as that of smooth piles for dense dry silt at relative density of 68 % for k=0.28.

It should be pointed out that the shape of the load-displacement curves for the smooth and rough piles is similar as shown in figures (3) and (4). the axial load is approximately constant, but in the case of smooth piles a very little reduction in axial load is shown, with the amount depending on the density of silt.

The ultimate displacement of the model pile P_f to mobilise the maximum shaft resistance is relatively small and is dependent on surface roughness of the piles as shown in tables (2) and (3). In the case of smooth piles, P_f ranges from (3 -7) mm, which corresponds to about (1.5 -3.5) % of the length of pile-soil contact, whereas, in the case of rough piles, it ranges from (4.5 -7) mm corresponding to about (2.25 - 3.5) % of the length of the pile-soil contact.

The pile displacement at failure values corresponding to the tests on specimens in tables (2) and (3) indicate that there is a general trend of increasing pile displacement at failure with increasing lateral confining pressure. The results clearly show that the rough pile requires a little more displacement to reach failure, which in turn generates more deformation of the soil element.

In summary the test results indicate that the amount of pile displacement to achieve the maximum load and the work done on the soil element increase with increasing pile-surface roughness and lateral confining pressure.

FIG.5- Shaft resistance versus horizontal confining pressure for smooth model piles [S1-S6]

FIG.6- Shaft resistance versus horizontal confining pressure for rough model piles [R1-R6]

2-Influence of lateral confinement

The shaft capacity Pu, increases directly with increasing lateral confining pressure. A similar observation was reported in [1], [3] and [4] for a pile in a sand and kaolinitic clay. From figures (5) and (6) it is observed that the load capacity depends on lateral confining pressure. Furthermore, the rate of increase of Pu depends on the surface roughness of the piles and it is much higher in rough piles than in smooth piles**.**
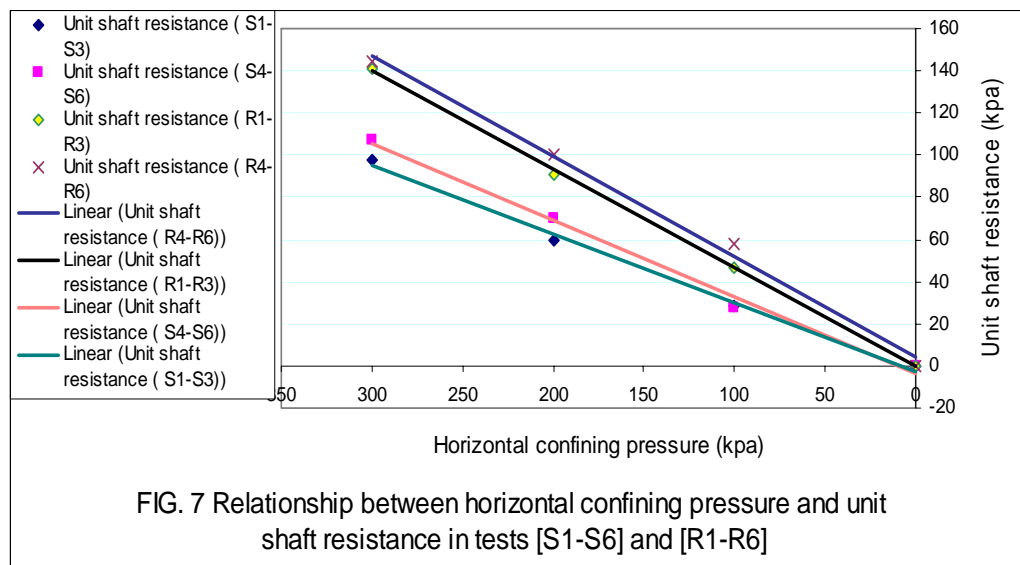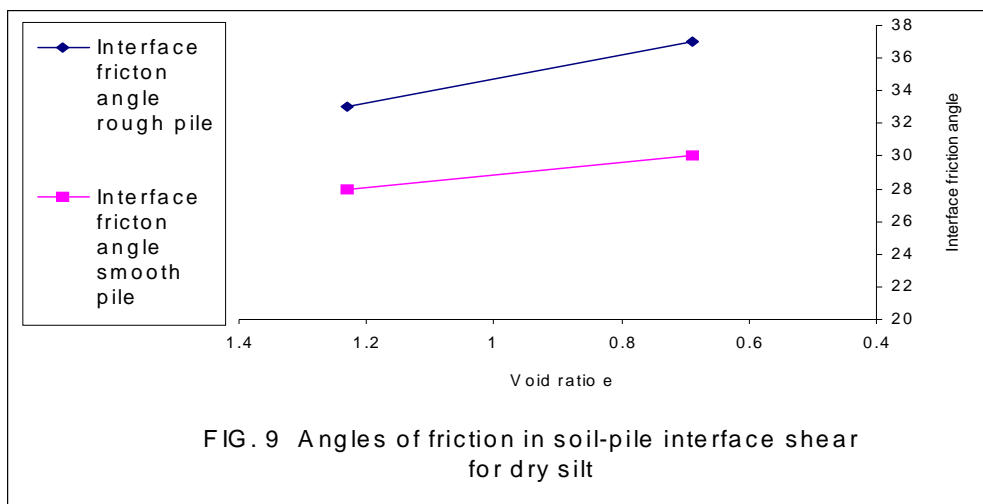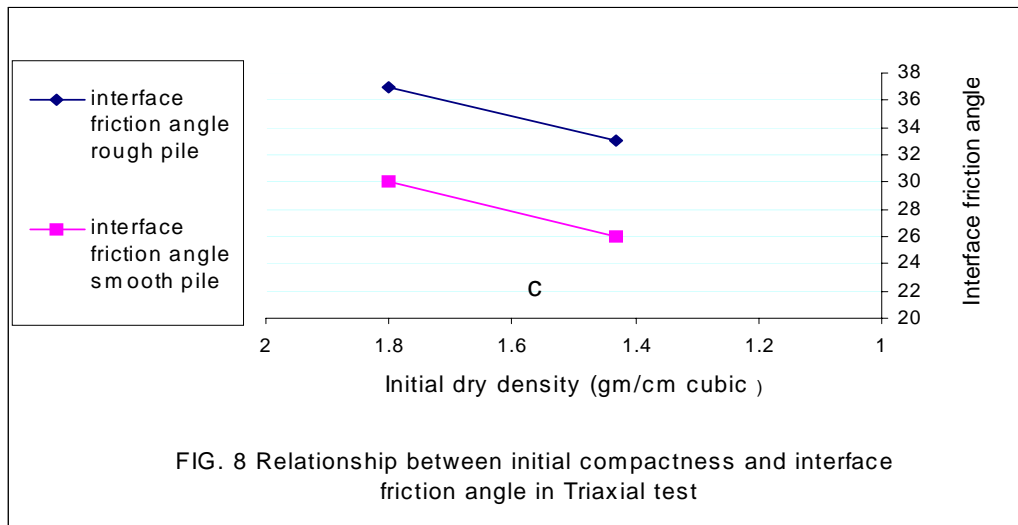
3-Load displacement response

Typical axial load-pile head displacement curves obtained from the constant rate of displacement tests are shown in figures (3) and (4). The ultimate shaft capacity Pu increases with increasing horizontal pressure applied on the lateral surface of the silt specimen. In case of rough pile model tests the magnitude of the axial load stayed constant after reaching the ultimate displacement P_f ,where it showed a very slight reduction of the axial load at displacement larger than P_f in case of smooth pile. This was attributed to the packing of grains of silts.

The test results indicated that very little pile displacement is required to reach the maximum axial load and the failure of the friction pile, which equal 20 % d in case of smooth pile surface, and 25 % d approximately in the case of rough pile, where d is the pile diameter.

4-Angle of pile-soil friction

The angle of pile-soil friction is seen to be different for each soil specimen tested, depending on the model pile test arrangement (pile diameter, length of pile-soil contact, and pile surface roughness), the initial density of the soil specimen, the void ratio and the relative density. The value of (tanδ) is affected significantly by the surface roughness of the model pile. This is demonstrated by the test results as shown in figure (7). As seen in figures (8) and (9) the peak interface friction angle δp is affected by the roughness of the pile and the relative density of the silt.

FIG. 7 Relationship between horizontal confining pressure and unit shaft resistance in tests [S1-S6] and [R1-R6]

FIG. 8 Relationship between initial compactness and interface friction angle in Triaxial test

FIG. 9 Angles of friction in soil-pile interface shear for dry silt

SUMMARY

The test apparatus described to measure the load transfer along the smooth and rough shaft surface of an aluminium model pile erected in a specimen of dry silt proved to be a useful tool in studying shaft resistance behaviour. It offers certain features that can be advantageous in analysing the pile-soil interaction.

The results-based on tests on 12 samples of a dry silt with different initial compactness-show that the angle of pile-soil friction is dependent on the surface roughness of the piles, the relative density, the void ratio and the stress level.

The magnitude of displacement to mobilise the maximum shaft resistance is relatively small, and is dependent on the length of the pile-soil contact surface and the surface roughness.

CONCLUSION

On the basis of the tests which were done 6-smooth piles and 6-rough piles) the following conclusion can be drawn:

1- In this study, the shaft capacity of rough piles is greater-as much as (1.50 – 1.71) than that of similar smooth piles in loose dry silt, where it is ranges (1.39 – 218) higher than that of similar smooth piles in dense dry silt.

2- The shaft capacity of pile, P_u increases directly with increasing lateral confining pressure.

3- The rate of increase of P_u with confining pressure is much higher in rough piles than in smooth piles

4- A small displacement of the pile is sufficient to mobilise the shaft capacity, and varies with surface roughness of the piles and the confining pressure on the soil element surrounding the pile.

5- The displacement of failure ranges from (3 - 7) mm in the case of smooth piles , whereas it ranges from (4.5 - 7) mm in the case of rough piles .

6- Loading the pile with a vertical load causes downward displacement of the pile, which causes downward deformation of the top surface of the soil element.

7- The value of interface friction angle increases with increasing of initial compactness of the silt, relative density, roughness of pile surface and lateral confining pressure.

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