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ESTIMATION OF NEGATIVE SKIN FRICTION IN DEEP PILE FOUNDATION USING THE PRACTICAL AND THEORETICALLY APPROACHES

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ABSTRACT

The majority of the skyscraper configurations have immense weight exchanges to the foundations which make the selection of footing type "raft" unimaginable, particularly when the bearing limit of the associate soil foundation media is not adequate to maintain such expense of the high rise building weight. Thisreseachfocuseson reviewingthe negative skin friction and estimation its value; using the practical, numerically and theoretically approaches. Comparison will be made between Joseph E. Bowles approach and his output with a considered particularcase. A numerically investigation was carried out on finite elements modeling(PLAXIS) of a pile subjected to negative skin friction due to the lowering of the groundwater table. The settlment values were calculated in the PLAXIS 3D program where this value was considered as a criterion for calculating the settlment in 2D against which negative friction values were calculated. The results obtained from the PLAXIS 2D program were far from the field reality but with the corrected values of the compression modulus the program results approach the results of the field.The theoretical calculation is used to estimate the value of Negative skin friction, but it should use the suitable method in the computation. In this study, the β method is discovered as a appropriate method of the calculation for the deep piles in the deep soft soil area.

Keywords: pile foundation, bearing capacity, negative skin friction, β method.

INTRODUCTION

All collected and recorded data demonstrate that piles bearing on the very extremely capable material, "the negative skin friction along the pile surface can be considered as the sources of vastfor expansive drag loads" [1].

Instantly after a pile is introduced in the ground, the ground layer is reconsolidated from the unsettling influence brought on by the establishment of the pile, regardless whether it was driven or something else.

The pile test announced by [2-3] began in 1968 and estimations were taken until 1983, i.e., for a long time [1]. The test is especially fascinating in the light of the fact that it includes the impact of applying a static load to the pile head and not only perceptions of the improvement of the drag load in the pile.

"Negative skin" friction is an unusual pile-soil interaction phenomenon that happens in driving piles into the soil has filled in, upon or at the end stage of the accomplishment of piling procedure.

Load on the pile foundation

Figure 1gives an explanation for the system of acting forces on the pile, some of which directly affect the head of the pile, the yare the forces generated due to the weights and loads. The second type acts are a result of the phenomenon of liquefaction, which gives rise to side stresses affecting the body of the pile dissolved in the soil due to shaking as a result of the earthquake [4-7]. While there is a third source of stresses and forces on the pile and generated from the pressure of water and this is what is frequently obtained in marine structures [8].

Piles commonly found as sets that are all combined by means of a pile cap [8] as shown in Figure-2. “The load carrying mechanisms of the piles are end bearing and friction piles carry vertical compressive loads partly by means of resistance offered by the hard stratum at the tip of the pile and partly by the friction developed between the pile shaft and soil. Or pure friction piles carry the major part of loads only by means of friction developed between a pile shaft and soil; and pure end bearing piles only by means of bearing resistance at the tip of the pile. In both the above cases, lateral loads are carried by the lateral resistance offered by the surrounding soil” [8].

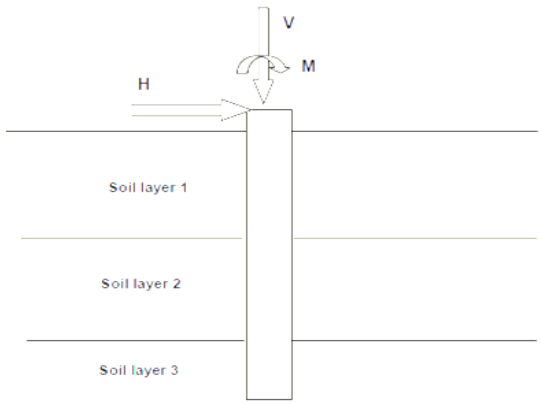

Figure-1. Characteristic loading illustration on a single pile inserted in soil (source: [8]).

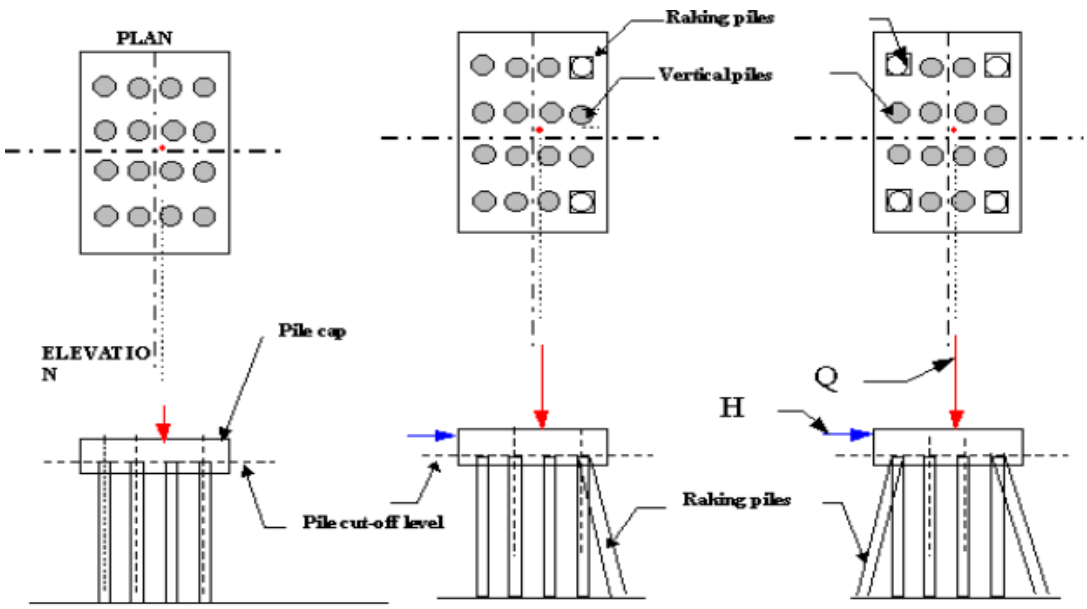

Figure-2. Schematic of load carrying mechanisms for pile groups [8].

Mechanism of negative skin friction generation in single and pile group

Figure-3 shows the negative skin friction of a single pile is given by [8]:

Negative skin friction load = Unit frictional resistance (downward)* Length of the pile above bottom of the compressible layer * Perimeter of the pile cross section

And total downward load= negative skin friction load + live load+ dead load

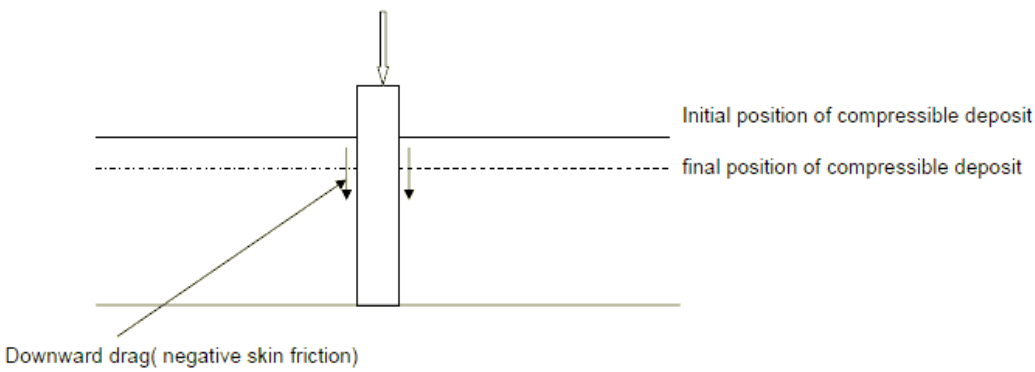

Figure-3. Negative skin friction (single pile).

For a pile group it can be assumed that there is no relative movement between the piles and the soil between them. Therefore the total force acting down is equal to the weight of the block of soil held between the piles, the weight of the piles and the pile cap and the download drag along the pile group perimeter due to negative friction see Figure-4.

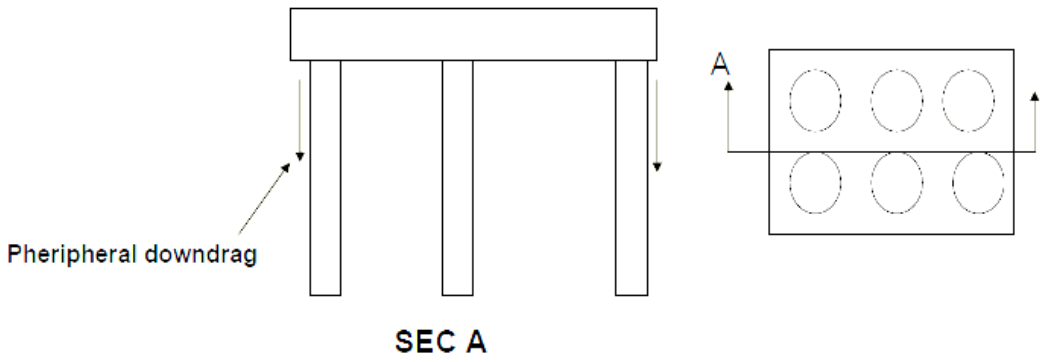

Figure-4. Negative skin friction (pile group).

EXPERIMENTAL WORK

Figure-5 shows the model of the work, data taking in this paper is as shown in Tables 1, 2 and 3:

Table-1. Public Sites in the test section.

Work site	Bridge name	Pier No.	Number of piles (root)	Pile length (m)	Pile diameter (m)	Cap dimensions
DK124	Tianjin Bridge	D18	12	52	1.25	12.5×9.1×2.5
		D19	12	52	1.25	12.5×9.1×2.5
		D20	10	51	1.25	12.5×8.1×2.5
DK152	Tianjin Bridge	F371	8	50	1	10.4×5×2
		F372	8	50	1	10.4×5×2
		F373	10	47	1	12.5×7.1×2

Table-2. Soil investigation of DK124, D19.

No.	Thick-ness (m)	Density ρ(T/m3)	Severe γ(kN/m^3)	Severe saturation γ at(kN/m^3)	Void ratio e(m/t)	Cohesion c (kPa)	Internal friction angleφ(Degree)
1	2.5	\	17.7	18.00	\	14	8.5
2	5.8	1.87	18.3	18.62	0.912	15.9	9.2
3	10.8	1.86	18.2	18.51	0.923	11	10.6
4	21	1.98	19.4	19.53	0.723	25.6	13.5
5	26.25	1.97	19.3	19.46	0.735	20.9	16.7
6	27.8	2.08	20.4	20.60	0.629	21.4	15.4
7	32.15	1.91	18.7	18.88	0.877	96.8	14.6
8	43.4	1.93	18.9	19.17	0.789	35.6	15.5
9	47.7	1.96	19.2	19.45	0.737	42	21.3
10	54.5	1.98	19.4	19.73	0.688	43.8	17.1
11	59	2.04	20.0	20.20	0.622	8.9	32.7
12	71	1.98	19.4	19.73	0.688	43.8	17.1
13	74.6	2.04	20.0	20.20	0.622	8.9	32.7
14	81.5	1.96	19.2	19.48	0.741	44.7	15.5
15	83.1	2.06	20.2	20.40	0.56	13.7	36.2
16	85	1.96	19.2	19.48	0.741	44.7	15.5

In the filed the axial forces are measured according to the following table for different depths and thedifferentperiod within the construction process.

Table-3. Pile #6 axial force of the section of DK124, D19 (unit: kN).

From the top of the pile depth (m)	Casting Piertwo months ago	Casting Pier	Two months after girder	Six months after girder	Seven months after girder	Nine months after girder
	2009-9-7	**2009-10-13**	**2010-5-10**	**2010-9-22**	**2010-10-23**	**2010-12-22**
0.5	1165.5	1144.3	1345.5	1387.9	1610.2	1864.4
5	890.2	1133.7	1493.8	1493.8	1684.4	1695
25	583.1	784.3	1197.3	1239.6	1345.5	1430.2
31	413.6	572.5	974.9	1006.6	1123.1	1165.5
51.5	0.7	201.9	487.8	519.5	540.7	551.3

Pile No. 6 canbe shown in the following Figure-5

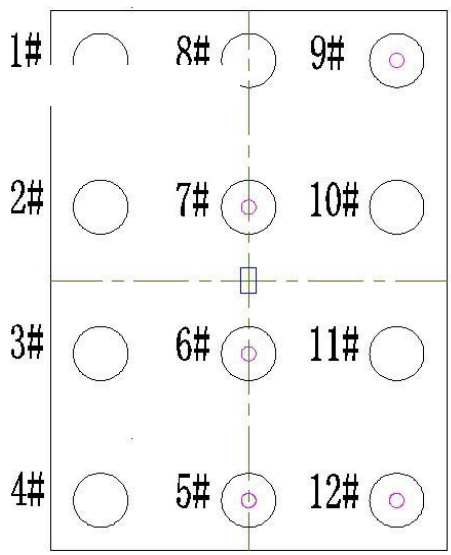

Figure-5. Pile No. 6 layout of DK124, D19.

In each period loads, the pile axial cross section of the test is summarized in Table-3, whereby the pile shaft trying to plot as shown in Figure-6.

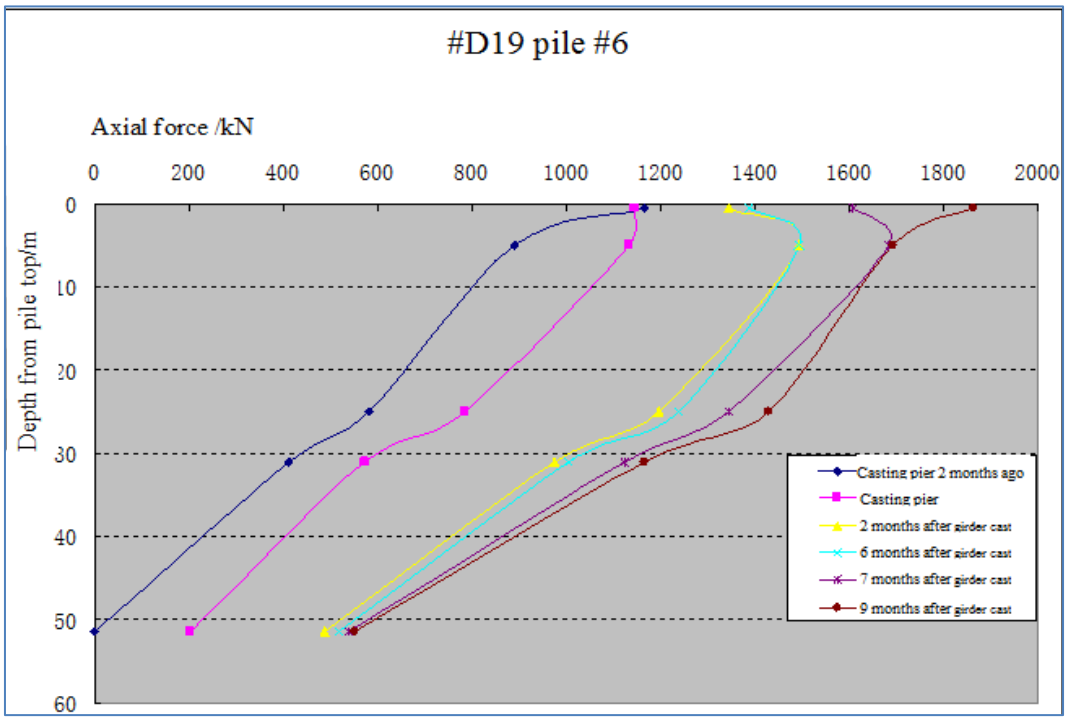

Figure-6. #6 pile: axial force.

Skin friction distribution and the development process

Skin friction changes in axial force by the calculated values obtained.

$$q_{si} = \frac{Q_i - Q_{i+1}}{\pi D l_i}$$

Where q_{si} is the lateral frictionbetween i-pile cross section and i+1 section (kPa);

Q_i The axial forcesofi-section (kN);

l_i The distance betweeni-section with the first i+1 sections (m).

Between the two tests, sections under axial force can be described as the difference between the average friction pile sections, summarized in Table-4.

Table-4. #6 pile pier average frictional resistance of the cross-section data.

Average thickness (m)	**Casting Pier two months ago**	**Pier in the pouring**	**Two months after girder**			**Six months after girder**	**Seven months after girder**	**Nine months after girder**	
	2009-9-7	**2009-10-13**	**2010-5-10**				**2010-9-22**	**2010-10-23**	**2010-12-22**
	Friction (kPa)		**Friction** (kPa)	**Friction** (kPa)	**Friction** (kPa)	**Friction** (kPa)	**Friction** (kPa)		
4.5	15.6		0.6	-8.4	-6.0	-4.2	9.6		
20	3.9		4.5	3.8	3.2	4.3	3.4		
6	7.2		9.0	9.4	9.9	9.4	11.2		
20.5	5.1		4.6	6.1	6.1	7.2	7.6		

Table-4 shows the practical results of the field test. Therefore, it should do theoretical calculations using the equations, as following:

$$L_1 = \frac{L-Hf}{L1}\left(\frac{L-Hf}{2} + \frac{q_\circ}{\gamma'}\right) - \frac{2q_\circ}{\gamma'} \quad (1)$$

$$P_n = \alpha' p' (q_\circ + \frac{\gamma' L1}{2}) L1K \quad (2)$$

From Equation $p_{pf} = \int_{L1}^{L} \alpha'_2 \, p' \bar{q} k d_z + p_{np}$ (3)

$$P_n = \alpha' p' (q_\circ + \frac{\gamma' L1}{2}) L1K$$

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it can be found that the following results noted that some deception was reported by [1]. The value of negative skin friction is found as 16.3 kPa and it is high value comported with field results.

From Equation 2, but using L1=4.5m taking from the field results:

From field results L_1=4.5m

Estimated length of pile(m)=	52
Fill density(KN/m^3) =	8.19
"Total pressure due to fill($q_\circ$,KN/m^2)=	20.47
Underlying soil Density (γ',KN/m^3)=	8.81
Internal angle of friction (ϕ,deg)=	9.2
K value= 1-sinϕ=	0.84"
ὰ value =0.667* TAN(ϕ)=	0.106
Pile dimension(m)=	2.25
Pile perimeter(p',m)=	3.92
"Position of neutral axis(L1,m)=	4.5
Load increase due to –ve skin friction (kN)=	35"
Surface area of pile (m^2)=	135
Negative skin friction(kpa) =	2.03

The results of Negative skin friction is 2.03 kPa for L1=4.5m and it is low value comported with field results.

In addition to the above calculations it can do other calculation using β- method

β- method:

f=μ*β

μ= γ'_f*h_f+γ'*h

= (8.19*2.5)+(8.81*2.5)

= 42.5 kN/m^2

β=0.2

f=0.2×42.5 = 8.5 kPa

As shown from the above result, it is noticed that the value of negative skin friction is maintained as 8.5 kPa; and this value is accurate, because it is very close to the field results which maintained the field negative skin friction is 8.6 kPa, and this method can be adopted to calculated the negative skin friction in the deep pile foundation in the deep soft soil area because the error in this method is 1.163%.

From the above calculations, we can see the results of Negative skin friction calculations are calculated as follows:

16.3kPa, 2.03, method is 8.5 kPa. In the field, the value of Negative skin friction is measured as 8.4kPa. So it can be seen that the method is giving good results compared with other methods and can be adopted in the calculation of the Negative skin friction of deep pile foundations. The values of the negative friction were calculated by using the theoretical equations [6].

where several equations of theory were used and the results were shown as follows:

$P_n = \alpha' p'(q_\circ + \frac{\gamma' L1}{2}) L1 K1$-

Negative skin friction (kPa) = 16.3

2- <u>β- method</u>

f=μ*β

Negative skin friction (kPa) = 8.5

Results obtained from numerical simulation (PLAXIS 2D):

As shown from Figure-7 the piles model were simulated by PLAXIS finite elements. From the results of, it can be noticed that the negative skin friction occurred near of pile bottom at a depth about 40 m where the depth of pile is 52 m. It should be mentioned that the results of axial forces maintained from PLAXIS 2D were taken for both exterior and interior piles as illustrate in Figure-8.

PLAXIS 2D program takes into consideration the results of deferent depths for deferent piles. In the 2D model four piles were represented while they are twelve piles according to design. The results from PLAXIS 2D for exterior and interior piles showed the axial forces for deferent depths from the bottom of the pile cap to the pile bottom up to depth of 52m. These results started from pile No.1 up to pile No. 11, while they are twelve as mentioned in the design and the bridge is established according to the last No. The results are finished up to 11 piles which means the design of the pile cap of bridge needs only for this number and it is enough to maintain the required parameters of the successful design.

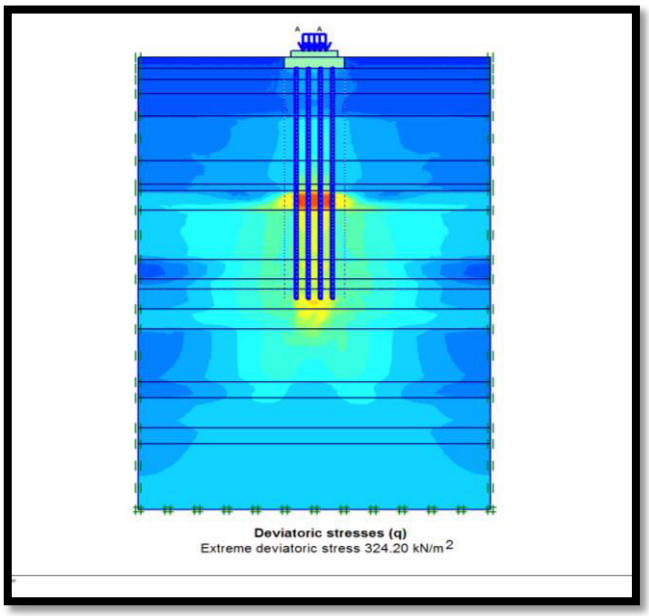

Figure-7. Modeling of piles by 2D PLAXIS.

The results of negative skin friction from PLAXIS 2D program are at a depth of 40.9 m with a value of 1.67 kPa and 1.29 kPa at 39.5m depth, these results are far away from the result measured in the field which is 8.4kPa at depth 4.5mas shown in Figures 8-10. This is may be attributed to the input values in the software represented by the compression modulus values where these parameters are suitable only for the shallow foundations and this project is established in a deep soft soil area. Therefore, the results of finite element PLAXIS

program cannot be trusted for the compression modulus tested for pressure between 100-200 kPa in the laboratory and should be modified using the correction formula suggested by [9-10]. Using the numerical analysis by PLAXIS finite element program indicates the required number of piles needed for the design is 11 instead of the 12 piles and it could be maintained a trusted results through modifying the compression modulus input values using the approach of deep soft soil area.

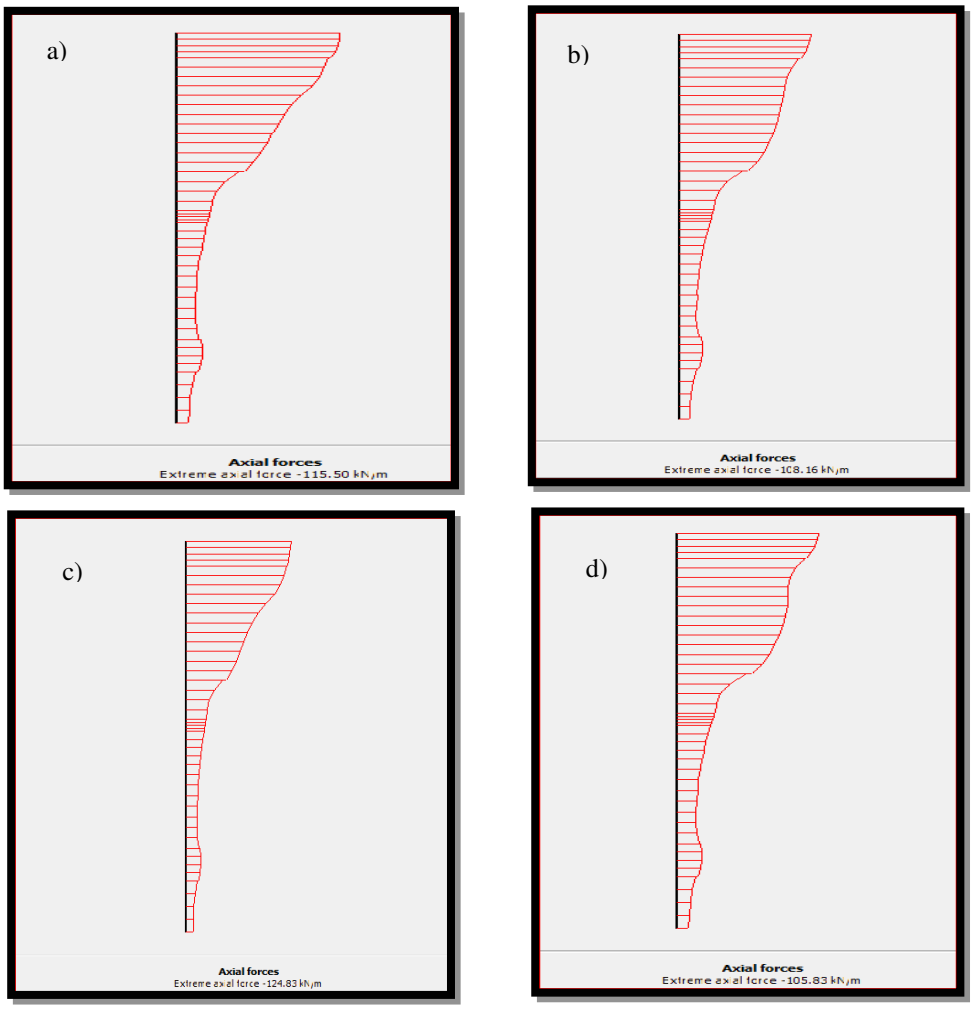

Figure-8. Axial force of pile: a) Pile No.1;b) Pile No.2; c) Pile No.3 and d) Pile No.4.

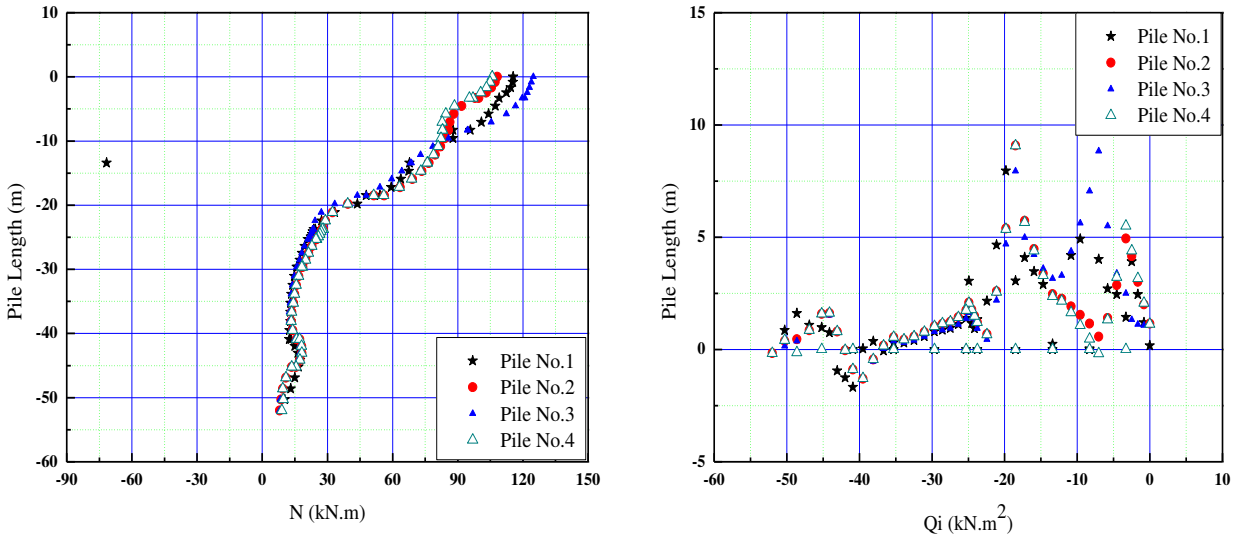

Figure-9. Axial force & negative skin friction of pile.

It is mentioned in the discussion above that the reason for the mismatch of field results with the results of the program is due to the inaccuracy of the values compression modulus inserted in the program the values of compression modulus were corrected by the following Figure-10.

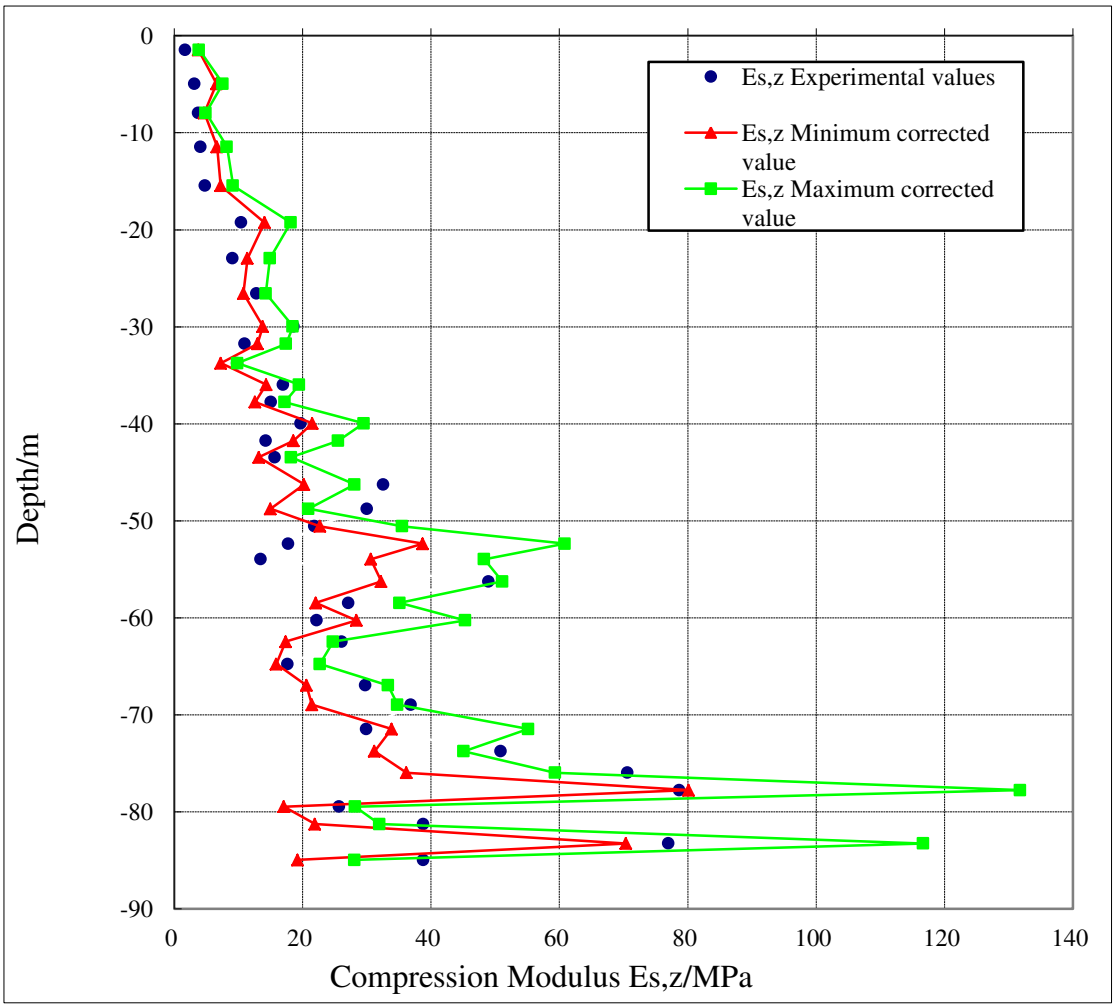

Figure-10. Compression modulus [11].

The values corrected were re-entered into the program and the following results were obtained see Figure-11:

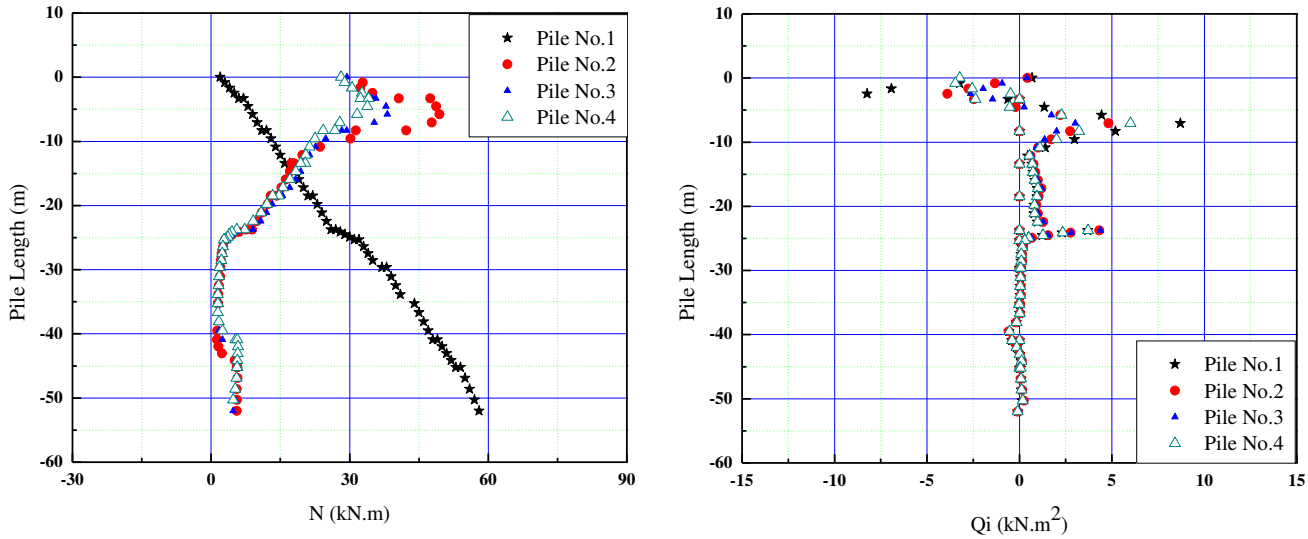

Figure-11. Axial force & negative skin friction of pile.

CONCLUSIONS

Numerous examinations have inspected the negative skin friction and many; those investigations have proposed distinctive ways to deal with evaluate the negative skin friction. In this paper, the methodology proposed by Joseph E. Bowels has been approved. For Negative skin friction, general conclusions are detailed below:

a. The extent of the negative skin friction is notably enormous and must be calculated for any design venture process.

b. The negative skin friction would be further for pile group rather than single piles for cases where non-cohesive soil overlaid by cohesive soils.

c. DK124 work site gives "Full Support situ three-span continuous beam" #D19 #6 pile pier (center pile) "pile reinforcement meter test results," and points to the corresponding axial force, lateral friction resistance, and tip resistance were analyzed, the following conclusions:

a) Axial force increases when the load gradually increased, finally becomes more stable in the pile and pile cap, pile axial force near the top is a larger range.

b) The maximum axial force of pile head is 1864.4kN, the maximum axial force of pile is 551.3kN at the bottom of the pile.

c) The pile load reaction increases with enhancing the depth of the pile. The proportion of the pile load increases; the pile working load reaction force accounted for the percentage of pre-cast from the 0.0% at the top of the pile. By rising the applied dead load to the completion of loading, the percent of the axial force on the bottom of pile compared to the top of the pile is 29.6%, that is, of nearly 30% of the maximum dead load of the pile. This pile tip bearing is in the silt layer.

d) The maximum negative skin friction is obtained after two months of girder construction at a depth of 4.5m of pile foundation, and its value is 8.4kPa; smaller range of negative skin friction does not affect the overall bearing capacity of the pile.

e) In the range between 5m to 24.5m of pile depth, the development and changes of friction are small, about 4.5kPa, the value of a given specification limit is 20%.

f) The maximum friction pile is in the top of the pile under the dead load, as 11.2kPa, located away from the depth of 24.5m to 31m of the pile, where the soil is powder (sand) soil layer, for the proper specification limits given about 15%.

g) After the depths 31m of the pile, changes in the development of friction are relatively clear that a maximum of 7.6kPa, the value of a given specification limit is 16%.

h) Pile tip resistance increases while increasing the working load, but with the increase of the "pile end resistance load growth rate" gradually slows down.

i) The maximum pile reaction is 449.5kPa, for the relevant norms for a given limit of 40%.

j) Regarding the capacity, the pile has an adequate safety margin. Work under constant load factor of safety greater than 2in order to meet regulatory requirements.

k) In this study, theoretical formulas are converting to a program that could compute the negative skin friction for piles embedded in non layered soil.

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