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Optimization of Pile Length for Basal Reinforced Piled Embankment

Abdallah Mohamed Kamal[a], Mohammed Mounir Morsy [b], Hossam Eldin A.Ali[c]

a. MSc. Researcher - Department of Structural Engineering – Faculty of Engineering – Ain Shams University (abdallahmarzok2020@gmial.com)
b. Professor of Geotechnical Engineering, Department of Structural Engineering - Faculty of Engineering – Ain Shams University (mohamed.monier@iacg.com.eg)
c. Professor of Geotechnical Engineering – Department of Structural Engineering - Faculty of Engineering – Ain Shams University (Hossam_e_ali@eng.asu.edu.eg)

الملخص العربى:

يعد البناء على التربة الرخوة أمرا صعبا نظرا لقوى القص المنخفضه جدا ومعامل التشوهات المنخفض للتربة الرخوة التي لا يمكنها تحمل الأحمال الخارجية دون حدوث تشوهات كبيرة. تصميم السدود والجسور على التربة الرخوة يثير العديد من المخاوف المرتبطة بانشاء الجسور بسبب تعرض التربة لحمل كبير على مساحة كبيرة.

يهدف هذا البحث إلى دراسة تحسين طول الخوازيق لنظام الخوازيق العائمة وكيفية تحديد الطول الحرج الذي يتطلبه طول الخزوق المطلوب بحيث يتم دعم حمل الجسر بأكمله بواسطة الخازوق وسيتم تنفيذ ذلك باستخدام النمذجة العددية باستخدام تقنية العناصر المحدودة. سيتم تطبيق النماذج العددية على دراسات سابقة متبوعة بإجراء دراسة حدية للتحقق من العوامل المختلفة التي تؤثر على تحديد الطول الحرج للخوازيق.

Abstract:

Construction on soft soils is very challenging due to the extreme low shear strength and deformation modulus of soft soils, which cannot sustain external loads without having large strain. Designing dams and embankments, on soft soils raises several concerns, which are related to the fact that embankment impose a significant surcharge over wide.

This research aims to study the pile length optimization of the floating-piles system and how to determine the critical length that the pile length at which the entire embankment load is supported by the floating pile. The required pile length is defined as the pile length at which the entire embankment load is supported by the pile. This will be carried out using numerical modeling utilizing the finite elements technique. The numerical models will be applied on previous cases studies followed by performing a parametric study to investigate the different factors affecting the determination of the critical length of the piles

Keywords:

Floating pile, Critical length, Piled embankment, Soft soils

1. Introduction:

The interaction between clay soft soils and different structures results in many complications in terms of geometric behavior in both the short and long term. Projects that built on soft clay are projects of very high danger for the safety, cost and time so that it is requiring a very precise description of the geometrical characteristics of the soft clay.

The load transfer mechanism in basal foundation is a combination of the soil arching phenomenon and the effect of the reinforcement layer. The tensile strength of the reinforced layer is the remaining load from the load transfer through soil arching. Many works have been published in the past to calculate the load transferred to the piles due to arching (Terzaghi et al. 1943; Carlsson et al. 1987; and Hewlett et al. 1998). Based on these works, guidelines for piled embankment design such as British Standard BS8006 were developed.

Design methods for (GRPES) geosynthetic-reinforced piled embankment system are based on a wide range of conservative assumptions that give rise to conflicting results Smith et al. (2007) They are good for the preliminary design of piled embankments as these designs are simple to use and give conservative results but questionable for the detailed design. According to Lawson et al. (1995) to accurately analyze (GRPES), numerical techniques are required especially when it comes to serviceability criteria.

Geotechnical investigations were administrated for major comes at Port same Governorate. In this research, previous geotechnical engineering studies were all collected (Hamed et al. 2017; Hamza et al. 2005; Hamza et al. 2013) in different places in Port Said. Figure 1 shows the soil profiles for all studies.

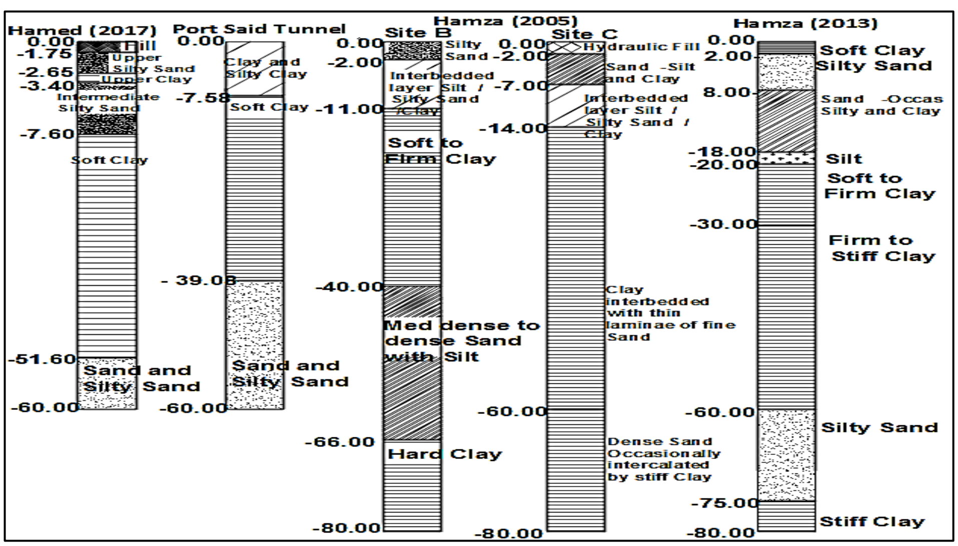


Figure 14soil profiles of Port Said Studies.

2. Finite element models and parameters

Full 3 D modeling approach adopted in this study was used to develop a 3-D model used in this study. The analysis steps carried out by Liu et al. (2007) were followed for the validation of the methodology adopted in the present study. Comparisons were made between the results from the four models with floating and end-bearing piles with lengths (20, 30, 40, and 53 m) of the measured variations in stress, settlement, axial forces, skin friction, shear forces, bending moment, and distortion angle. Figure 2 shows representing the right half of the embankment geometry due to the domain on account of the line of symmetry about its mid-section. A 3 m height of embankment with crest width 18 m and having side slopes of 1V:1.5H. A working platform with depth of 0.50 m lying on the piles. Piles of diameter (d) 1 m arranged in a square grid pattern and at 3 m center-to-center spacing (s).

The profile of soil used in this model is (Hamed, 2017). The profile consists of a silty sand layer with thickness of 7.6 m. The second layer is soft soil with permeability Kh= 2.5×10-3 m/day and Kv= 8.3×10-4 m/day with thicknesses of 5 m. The third layer is soft soil with permeability Kh= 5×10-3 m/day and Kz= 1.7×10-4 m/day at depth of 44 m. The last layer is sand with thickness of 8.4 m. The groundwater table located at 8.6 m below the ground surface. Table 1 and 2 show soil properties used in this model.

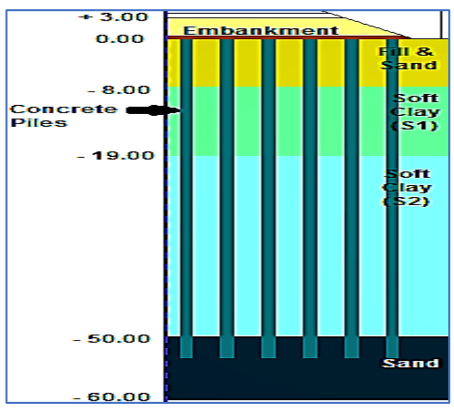


Figure 15 Pile embankment system.

Table 8 Soil properties used in numerical model.

Layer	Unit Weight kN/m^3	K_0	C' (kPa)	Φ' (^{0})	Eu^{50} (MPa)	E_{oed} (MPa)	Vertical Permeability m/day	Horizontal Permeability m/day
Silty Sand	**17**	**0.52**	**0**	**29**	**20**	**20**	**1**	**1**
Sand	**18**	**0.43**	**0**	**35**	**30**	**30**	**4.3×10^{-3}**	**4.3×10^{-3}**
Embankment	**17**	**0.5**	**10**	**30**	**20**	**20**	**1**	**1**

Table 9 Soft Clay properties used in numerical model.

Layer	Unit Weight kN/m^3	C' (kPa)	Φ' (^{0})	λ^*	M	K^*	Vertical Permeability m/day	Horizontal Permeability m/day
C 1	16	0	23	0.109	0.81	0.030	8.3×10^{-4}	2.5×10^{-3}
C 2	16	0	23	0.109	0.81	0.030	1.7×10^{-4}	5×10^{-4}

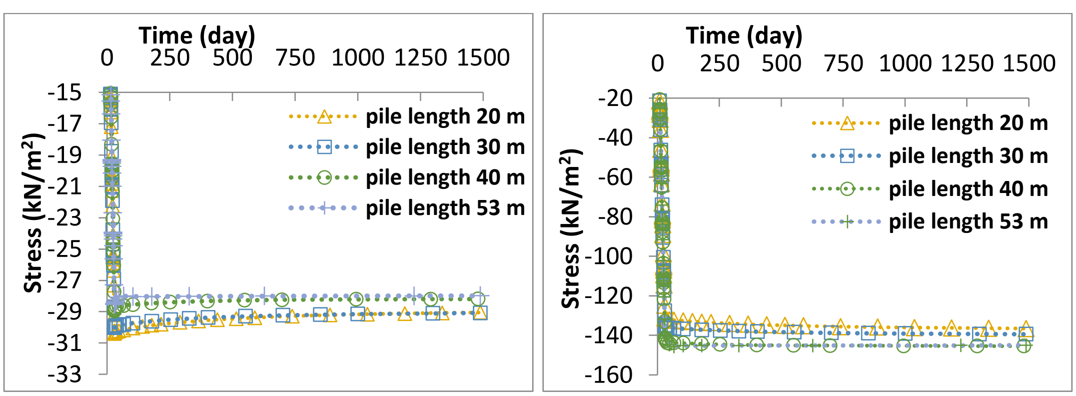
3. Results and discussion

Stresses Variation with Time

Figures 3 a) and b) show the comparison between stress acting on soil surface and pile head for different cases. Figure 3, a) Shows the variation of stress acting on the soil surface at the middle of embankment after the consolidation period of 1490 days. Generally, the stress acting on the soil surface in the middle of the embankment in the case of the floating pile is higher than the stress in the case of end-bearing piles. The stresses acting on the soil surface decrease with increase in pile length due to the arching coefficient improved with increase pile length.

Figure 3, b) shows the variation of stresses acting on pile head at the middle of embankment after the consolidation period of 1490 days. The stresses increase with the increase of pile length and reach a maximum at pile length 40 and 53 m. The stresses in case of end bearing pile (53 m) constant during consolidation period. In case of floating piles (20, 30 and 40 m) stresses increase during consolidation period.

The improvement in soil arching can be observed by increase stresses acting on the pile and decrease stresses acting on the soil surface between the piles. In the case of pile length 40 m, and 53 m the stress on pile head increase with increase pile length and stress on soil surface decrease with increase pile length.

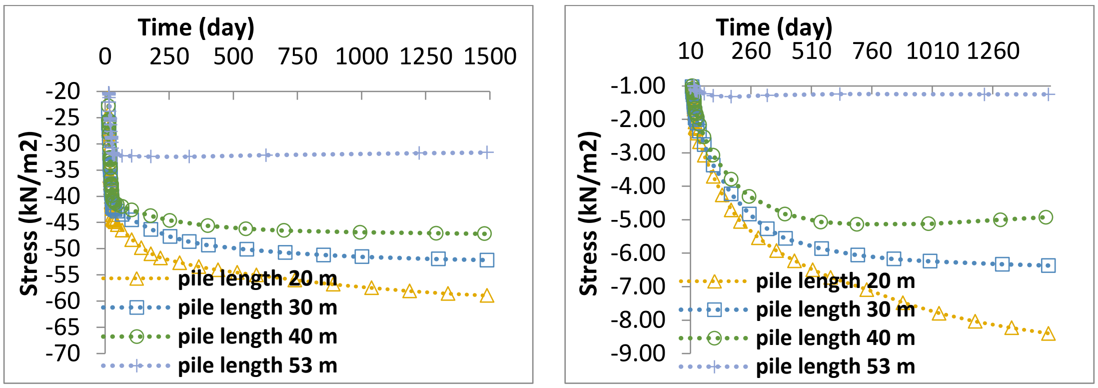


a) Stresses acting on soil surfaces.

b) Stresses acting on piles head.

Figure 16 Comparison between stress acting on soil surface and pile head for different cases at the middle of embankment.

Figure 4 a) and b) show the stresses acting on the soil surface and the pile head at the toe of embankment. the stress acting on pile head increase with increase pile length. The minimum stress acting on the pile head in the case of an end-bearing pile. The stresses acting on the soil surface decrease with increase pile length. In case of floating piles(20, 30 and 40) the stress increase during consolidation period. In case of end bearing pile 53 m the stresses constant during consolidation period. The minimum stress acting on the soil surface in the case of an end-bearing pile.

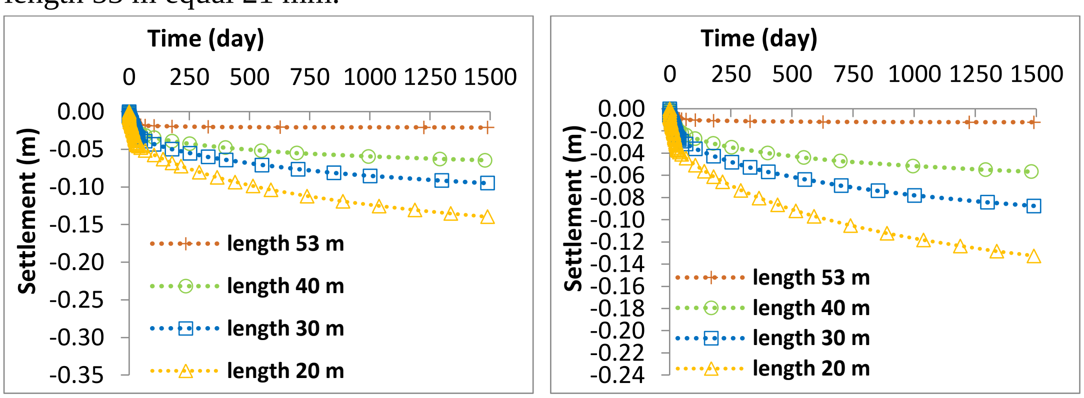


a) Stresses acting on Piles head. b) Stresses acting on soil surfaces.

Figure 17 Comparison between stress acting on soil surface and pile head for different cases at the toe of embankment.

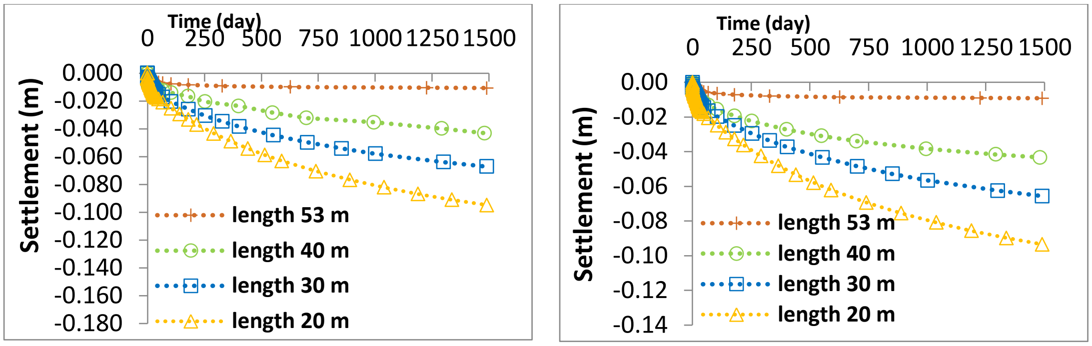
Settlement Variation with time

Figure 5 and 6 show the comparison between the settlement in the middle and toe of embankment on the soil surface and pile head. The settlement decrease with an increase in pile length. The settlement in case of the floating pile is higher than the settlement in the case of end bearing. The settlement in the middle of the embankment more than the settlement at the toe of the embankment. The maximum settlement is 340 mm in case of no pile after consolidation period of 1460 days. The minimum settlement acting on the soil in case of pile length 53 m equal 21 mm.



a) Settlement on soil surfaces b) Settlement on piles head.

Figure 18 Comparison between the settlement on soil surfaces and piles head at the middle of embankment



a) Settlement on soil surfaces

b) Settlement on piles head.

Figure 19 Comparison between the settlement on soil surfaces and piles head at the toe of embankment.

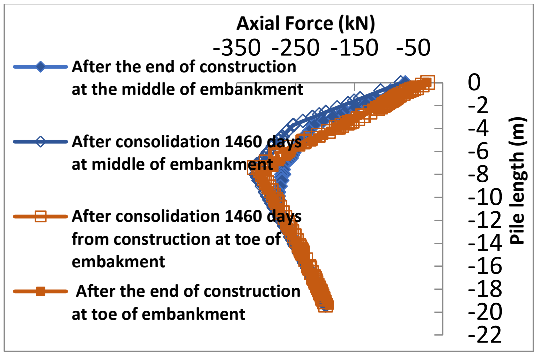
Axial Forces

Figure 7 shows comparisons between axial forces analysis. In general axial forces increase with increased depth due to negative skin friction and the maximum value of axial force located at the neutral plane level. As shown in figure 7 no change in the neutral plane depth after construction and after consolidation 1460 days but the change happen when the pile length change. In case of end bearing piles the axial force showed a significant increase because of the continuous transfer of negative skin forces to the pile over the full length of the pile as shown in figure 7 c).

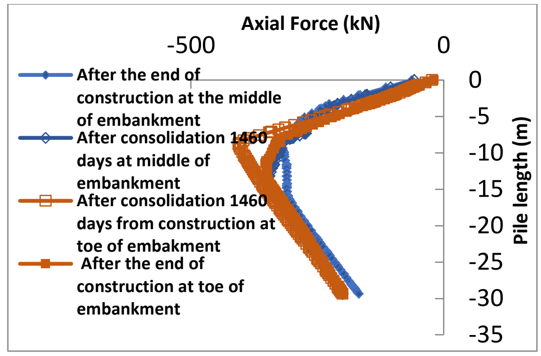
Table 3 shows the difference between axial forces value and neutral plane depth at the end of construction and after consolidation 1460 days at the middle and toe of embankment.

Table 10 Comparisons between axial forces values and neutral plane depth.

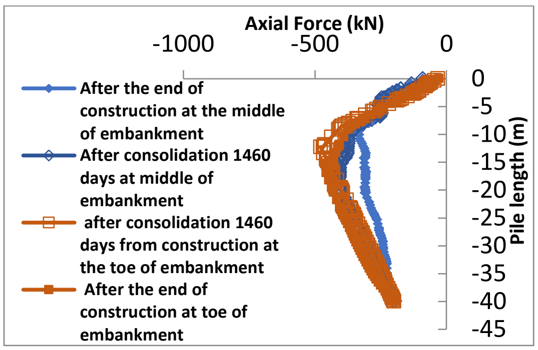
Pile length	Middle of embankment				Toe of embankment				Differences		
	After construction		After consolidation 1460 days		After construction		After consolidation 1460 days		Axial force	Axial force	Percent age of pile length
	Axial Force (kN)	Neutral Plane depth (m)	Axial Force (kN)	Neutral Plane depth (m)	Axial Force (kN)	Neutral Plane depth (m)	Axial Force (kN)	Neutral Plane depth (m)	Middle (kN)	Toe (kN)	
10	200	3.75	225	3.75	170	3.5	160	3.5	25	10	37%
13.5	250	5.5	275	5.5	270	6.5	250	6.5	25	20	40%
15	250	5.5	275	5.5	280	6.5	250	6.5	25	30	36%
20	300	7	325	7	320	7.4	311	7.4	25	9	35%
30	350	17	375	17	395	8	340	8	25	45	56%
40	400	25	500	25	435	15.4	400	15.4	100	35	62%



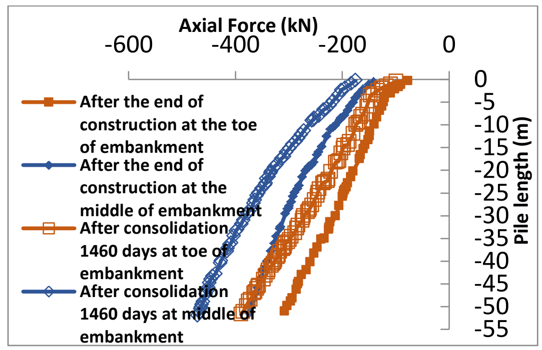
1) 20 m long pile.



b) 30 m long pile.



d) 40 m long pile.



c) 53 m long pile.

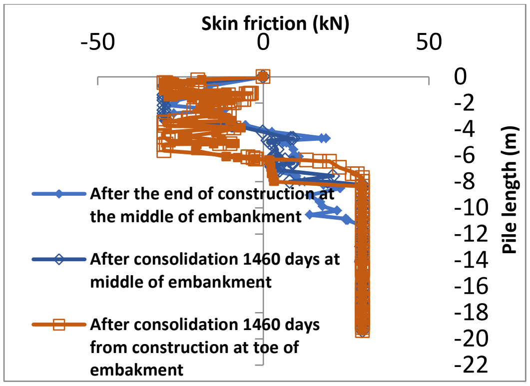
Figure 20 comparisons between axial forces analysis for floating piles.

Skin Friction

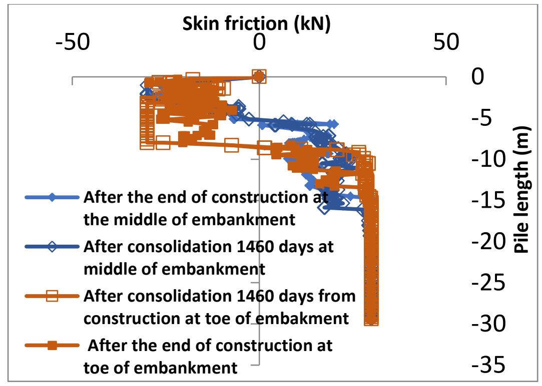
Negative skin friction is happened when the settlement of the soft soil is more than the settlement of the upper part of pile. In the lower section of the pile the positive shaft resistance is happened when the settlement of the pile is more than that of the soft soil. Figure 8 shows the distribution of skin friction force for different lengths of floating piles. In case of floating pile (20, 30 ,and 40 m) the neutral plane depth do not change after consolidation but change with change in pile length. In case of pile length 53 m (an end-bearing pile) the neutral plane is become near to the pile tip as illustrated in Figure 8 c). Table 4 shows the depth of neutral plane at the end of construction and also at the end of consolidation for each pile length.

Table 11 Comparisons between neutral plane depth at different cases.

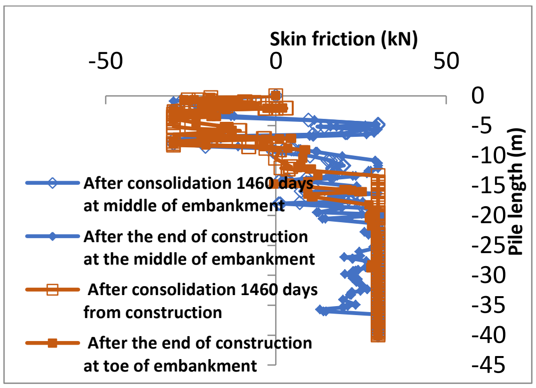
Pile length	Neutral Plane depth at middle (m)	Neutral Plane depth at toe (m)	Percentage of pile length at middle	Percentage of pile length at toe
10	3.5	4	35%	40%
13.5	4.5	6	33%	44%
15	4.5	6	33%	44%
20	4.5	7	22.5%	35%
30	5	10	16.6%	33.3%
40	5	10	12.5%	25%



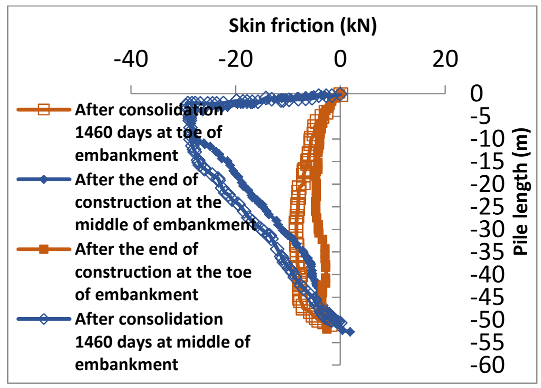
a) 20 m long pile.



b) 30 m long pile.



c) 40 m long pile.

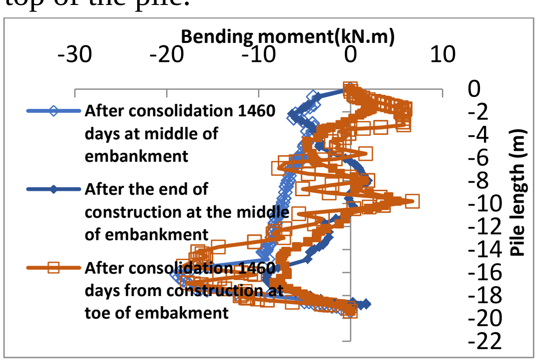


d) 53 m long pile.

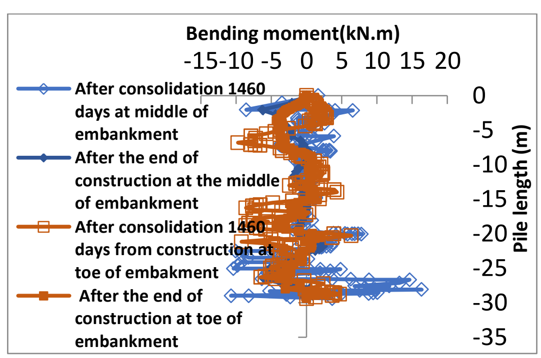
Figure 21 comparisons between Skin friction forces for floating piles.

Bending Moment and Shear Forces

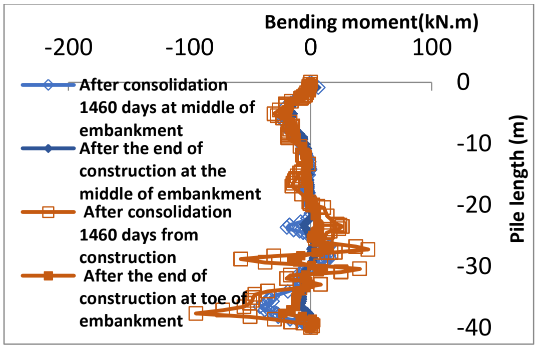
Figure 9 and 10 show the distribution of bending moment and shear force for different lengths of the pile. The bending moment and shear force are found to increase as the consolidation progressed and reached the maximum value near the end of consolidation. The maximum value of bending moment and shear force is located at a depth of (4/5)L from the top of the pile.

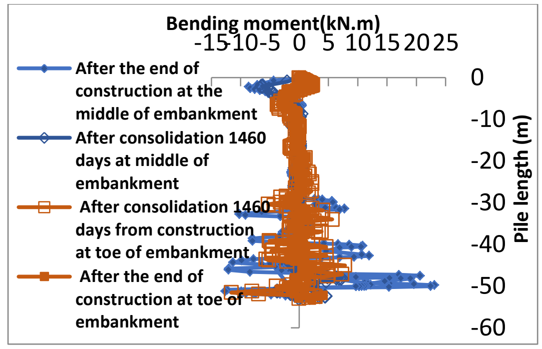


a) 20 m long pile.



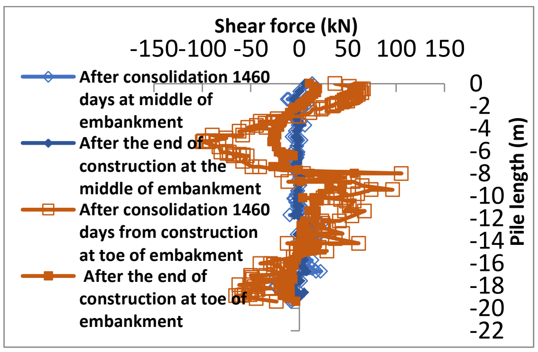
b) 30 m long pile.

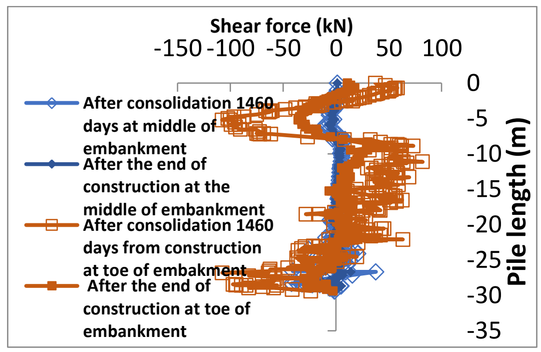




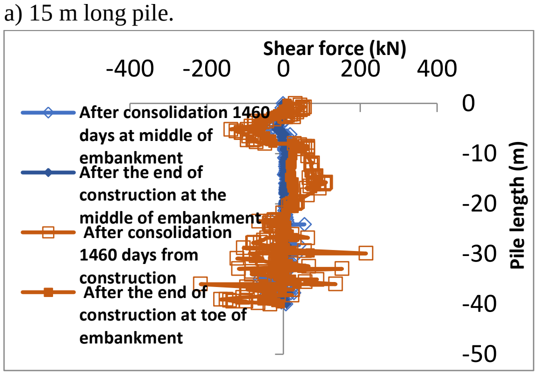
c) 40 m long pile. d) 53 m long pile.

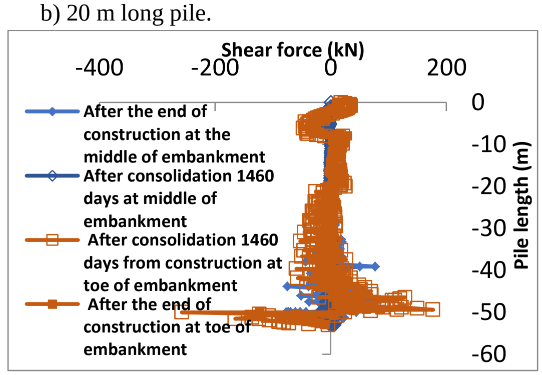
Figure 22 comparisons between Bending moment forces for floating piles.





a) 15 m long pile. b) 20 m long pile.





c) 30 m long pile. d) 40 m long pile.

Figure 23 comparisons between Shear forces for floating piles.

Distortion Angle

According to maintenance manual of road DGH No : 03/MN/B/ 1983 distortion is one of the road pavement damage. Distortion is a deformation happen due to foundation soil not good or not compacted good. Figure 12 shows comparisons between distortion of soil surface and pile head.

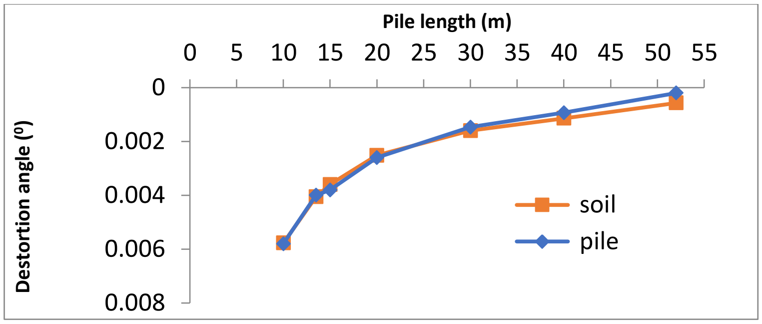


Figure 24 Distortion angle for soil surface and piles head.

6. Summary and Conclusions:

3D column models were utilized to hold out the constant studies on factors governing the performance of Geosynthetic strengthened concentrated hill Systems (GRPES), like the skin friction distribution on the pile length, axial force distribution. Full three-dimensional analyses were carried out to study the overall settlement behavior of the GRPES system. Stress on pile head increase with increase pile length. Based on the studies carried out, the following conclusions can be drawn:

- When the pile length is more than 20 m the stress on the soil surface decrease with increase pile length at the end of the embankment. It means that the soil arching improved when the pile length more than 20 m.
- It is preferable that the length of the pile should not be less than 60% of the depth of the soft soil layer to improve soil arching and stress on soil reduced at the middle and toe of the embankment.
- With increasing of pile length stress tend to decrease on edge piles which mean poor utilization of these piles.
- As the soil consolidation takes place, the pressure on foundation soil decreases and the loads transferred to the piles increases. This aspect is not considered in the design codes as they are based on undrained response of the GRPES system. The reinforcement forces also increase during the soil consolidation due to higher relative settlements. These aspects are to be considered in the revision of the design codes for piled embankments.
- The floating pile walls system has a great impact on the budget of the project as in the case of the high way route.

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