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EXTENDED ABSTRACT

Bearing capacity of a Post Grout Drilled Pile Group Adjacent to a Sandy Slope

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1. Introduction

In this research, using the finite element method and PLAIXS3D software, the bearing capacity of a post-grouted pile group installed at the crest of sandy slope is investigated. The effects of factors such as pile diameter, the ratio of embedded length to slope height, pile spacing, and the orientation of the linear pile group relative to the crest of slope on bearing capacity, efficiency coefficient, and tilting of cap are examined. In this study, pile groups with 3 different diameters, 3 different ratios of embedded length to slope height, and 3 different pile spacings were modeled at a distance equal to the pile diameter from the top of the sandy slope.

2. Methodology

In this research, the PLAXIS3D software was used for numerical modeling (Salem at el (2024)). The dimensions of the mesh elements were considered in such a way that they would not affect the results (Mahboubi at el (2023)). The dimensions of the model were chosen so that the stresses caused by loading were not close to the boundaries and did not have an effect on the final stress, minimizing the potential effects of the boundaries.

There are various methods for determining the bearing capacity of large diameter piles. In this study, the O'Neill (1999) method was used to determine the bearing capacity of the pile group. According to the O'Neill (1999) method, the bearing capacity of the pile group is calculated at a settlement equivalent to 5% of the pile diameter.

Soil was modeled using a hardening soil model. In numerical modeling, the pile and grout bubble were modeled using a linear elastic model (Thiyyakkandi at el (2014)). Soil, pile, and grout parameters are presented in Table 1. The modeled slope for the pile group with a diameter of 1 and embedded length of 20 meters, the modeled pile, and grout bubble are shown in Figure 1. Given that the piles in this study fall into the large-diameter pile category, volume elements were used to model the piles. In Table 1, the cohesion of sand is considered zero; however, to prevent numerical instability during model analysis, a small cohesion value (0.345 kilopascals) was considered for sandy soil.

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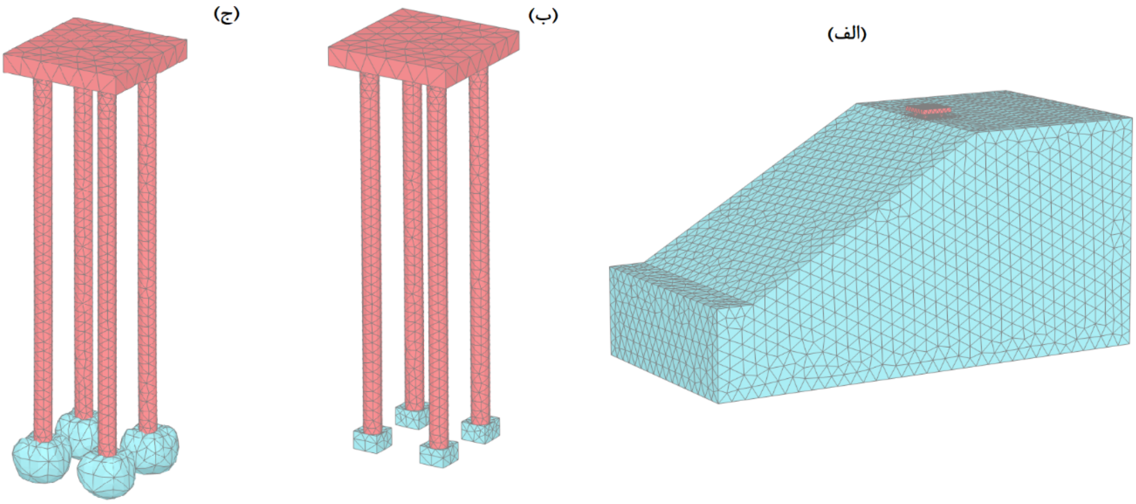

Fig. 1. a) 3D pitched roof model for a pile with a diameter of 1 and a embedded length of 20 meters b) Pile group and part of the soil under the tip that will be affected by grout grout c) Pile group and grout bubble formed around it

Table1. property of soil, pile and grout

parameter	unit	sand	pile	grout
C	KN	0	-	-
ɣ	KN/m3	16	25	20
ϕ	Degree	34	-	-
ψ	Degree	2.5	-	-
μ	-	0.3	0.2	0.2
E_{50}^{ref}	MPa	20	-	-
E_{ode}^{ref}	MPa	25	-	-
E_{ur}^{ref}	MPa	120	-	-
m	-	0.5	-	-
n	-	0.6	-	-
E	MPa	-	30000	20000

3. Results and discussion

3.1. Comparison of bearing capacity of piles adjacent to a slope and located on horizontal ground

In this section, the post-grouted pile group at the tip and the pile nongrouted on a horizontal ground and adjacent to the sandy slope were modeled. Table 2 shows that with increasing distance between piles, the tilting in post-grouted and nongrouted pile groups decreases. Comparing the results of Table 2 shows that the pile tip post-grouted process reduces the titling of pile groups adjacent to the slope. With increasing pile spacing, the effect of the post-grouted process on tilting reduction becomes more pronounced. The reduction in tilting of post-grouted pile groups compared to non-grouted pile groups for pile spacings of 3d, 4d, and 5d is 47%, 53%, and 60%, respectively.

The results of Table 2 show that in pile group installed on a horizental ground, the bearing capacity of the nongrouted pile group with pile spacing of 4d is higher than the bearing capacity of the pile group with pile spacing of 3d and 5d. However, in the nongrouted pile group adjacent to the slope, the bearing capacity of the pile group increases with increasing pile spacing. The results of Table 2 show that with increasing pile spacing in the post-grouted pile group, the bearing capacity of the pile group increases. The increase in bearing capacity of the post-grouted pile groups due to the increase caused by increasing spacing between piles in the pile group adjacent to the slope is more than the pile groups installed on a horizental ground. Increasing the pile spacing from 3d to 5d, the bearing capacity of the post-grouted pile group installed on a horizental ground and adjacent to the slope is 14% and 24%, respectively. The results in Table 2 show that as the pile spacing increases, the BCR coefficient increases, and the BCR coefficient of the pile group adjacent to the slope is higher than the BCR coefficient of the pile group installed on a horizental ground. With an increase in pile spacing from 3d to 5d, the BCR coefficient for post-grouted pile groups installed on horizental ground and adjacent to the slope is in the range of 1.30-1.35 and 1.35-1.39, respectively.

Comparing the results in Table 2 shows that in piles installed on horizental ground, the efficiency coefficient of the ungrouted pile group is higher than the efficiency coefficient of the post-grouted pile group at the tip. In piles adjacent to the slope, the efficiency coefficient of ungrouted and post-grouted pile groups increases with increasing pile spacing. The increase in efficiency coefficient due to increased pile spacing in the post-grouted pile group at the tip is greater than the increase in efficiency coefficient of the ungrouted pile group. With an increase in pile spacing from 3d to 5d, the bearing capacity and efficiency coefficient of ungrouted and post-grouted pile groups increased by 20% and 24%, respectively.

Table 2. bearing capacity of pile group

			Center-to-center distance of the piles (based on pile diameter)		
			3	4	5
horizental	Non-grout	Bearing capacity	22392	25725	24682
		efficiency coefficient	0.78	0.9	0.86
	Post-grout	Bearing capacity	29203	32603	33320
		efficiency coefficient	0.73	0.81	0.83
		BCR	1.3	1.33	1.35
Near Slope	Non-grout	Bearing capacity	18306	20639	22074
		efficiency coefficient	0.66	0.75	0.8
		RF	0.81	0.84	0.89
		Tilting	0.0026	0.0019	0.0015
	Post-grout	Bearing capacity	24678	28369	30612
		efficiency coefficient	0.65	0.75	0.8
		RF	0.85	0.88	0.92
		BCR	1.35	1.37	1.39
		Tilting	0.0014	0.0009	0.0006

3.2. Effect of pile diameter

In this section, the effect of pile diameter on the bearing capacity of post-grouted pile groups was investigated. Piles with diameters of 1, 1.5, and 2 meters were modeled at a distance equal to the pile diameter from the crest of sandy slope. Table 3 results show that increasing pile diameter leads to an increase in bearing capacity and pile group efficiency coefficient. The increase in bearing capacity of pile groups due to diameter increase is greater in post-grout pile groups compared to nongrout pile groups. By increasing the pile diameter from 1 to 2 meters, the bearing capacity of nongrouted and post-grouted pile groups increases by 2.74 and 3.08 times, respectively. The increase in pile group efficiency coefficient due to diameter increase is more significant in nongrouted pile groups compared to post grouted pile groups. With an increase in pile diameter from 1 to 2 meters, the efficiency coefficient of non-injection and post-injection pile groups increases by 16% and 5%, respectively. Table 3 results showed that the BCR coefficient increases with increasing pile diameter. This is due to the increase in injection grout pressure with increasing pile diameter and the resulting pre-compression of soil under the pile tip. The BCR coefficient for pile groups with diameters of 1, 1.5, and 2 meters is 1.37, 1.41, and 1.55, respectively. With an increase in pile diameter from 1 to 2 meters, the BCR coefficient increased by 13%. Table 3 results showed that the pile tilting in post-grout group pile was less than the suggested values (0.002), but in nongrouted pile groups with diameters of 1.5 and 2 meters, the pile tilting exceeded the maximum suggested value.

Table 3. bearing capacity of pile group

		Pile Diameter(m)		
		1	1.5	2
Non-grout	Bearing capacity	20635	38201	56460
	efficiency coefficient	0.75	0.77	0.87
	Tilting	0.0019	0.0023	0.003
Post -Grout	Bearing capacity	28369	53500	87354
	BCR	1.37	1.41	1.55
	efficiency coefficient	0.75	0.76	0.79
	Tilting	0.0014	0.0015	0.0018

3.3. Effect of the ratio of embedded length to slope height

In this section, the effect of the embedded length to the sandy slope height ratio (L/H) is investigated. Piles with L/H ratios of 0.33, 0.67, and 1 (with embedded lengths of 10, 20, and 30 meters, respectively) were modeled in 2 conditions: nongrouted and post-grout at the tip near the sandy slope. The slope height was 30 meters, and the slope angle was considered 30 degrees.

The results of Table 4 showed that with increasing the embedded length, the pile group bearing capacity increased, and this increase in bearing capacity was higher in the nongrouted pile group compared to the post grouted pile group. This indicates a decrease in the effect of the post-grout process on increasing bearing capacity with increasing pile embedded length. With an increase in embedded length from 10 to 30 meters, the bearing capacity of the non-grout and post-grout pile groups increased 2.74 and 2.59 times, respectively. The results of Table 4 show that with increasing pile embedded length, the BCR coefficient decreases. These results are consistent with the results of salem at el (2024) regarding individual post-grout piles. With an increase in embedded length from 10 to 30 meters, the BCR coefficient decreases by 31%. The results of Table 4 show that the efficiency coefficient of pile groups decreases with increasing embedded length. With an increase in pile embedded length from 10 to 30 meters, the efficiency coefficient of non-grout and post-grout pile groups decreases by 20% and 22%, respectively. With increasing pile embedded length, the pile group rotation decreased. The effect of the post-grout process on reducing tilting decreased with increasing pile head embedded length. The reduction in tilting due to the post-grout process for pile groups with embedded lengths of 10, 20, and 30 meters was 37%, 26%, and 20%, respectively.

Table 4. bearing capacity of pile group

		Embedded length(m)		
		10	20	30
Non-grout	Bearing capacity	9539	20639	35672
	efficiency coefficient	0.91	0.75	0.73
	Tilting	0.0027	0.0019	0.001
Post Grout	Bearing capacity	15302	28369	39674
	BCR	1.6	1.37	1.11
	efficiency coefficient	0.83	0.75	0.65
	Tilting	0.0017	0.0014	0.0008

3.3. Effect of the orientation of the linear pile group relative to the slope crest

In this section, the effect of the orientation of the 2×1(P), 2×1(v), 3×1(p), and 3×1(v) linear pile group relative to the crest of slope on the bearing capacity of the post-grouted pile group was investigated. Table 5 results show that the tilting of the post-grouted pile group is less than the head tilting of the non-grouted pile group. The reduction in tilting is more significant in piles parallel to the crest of slope due to the post-grouting process. The reduction in tilting due to the post-grouting process in 2×1(p) and 3×1(p) pile groups is 46% and 32%, respectively, and the reduction in tilting due to the post-grouting process in 2×1(v) and 3×1(v) pile groups is 25% and 23%, respectively, as shown in Table 6. The results of Table 6 indicate that the bearing capacity of the linear pile group perpendicular to the crest of slope is higher than the bearing capacity of the pile group parallel to the slope. Comparing the results in Table5 shows that the effect of the linear pile group orientation relative to the crest of slope on bearing capacity is less in the post-grouted pile group compared to the non-grouted pile group. The bearing capacity of the 2×1(v) pile group in non-grouted and post-grouted groups is 11% and 6% higher, respectively, than the bearing capacity of the 2×1(p) pile group. Similarly, the bearing capacity of the 3×1(v) pile group in non-grouted and post-grouted groups is 15% and 8% higher, respectively, than the bearing capacity of the 3×1(p) pile group.

The BCR coefficient of the pile groups parallel to the slope is higher than the BCR coefficient of the pile groups perpendicular to the slope. The BCR coefficients of 2×1(p) and 2×1(v) groups are 1.50 and 1.43, respectively, and the BCR coefficients of 3×1(p) and 3×1(v) groups are 1.45 and 1.37, respectively. With an increase in the number of piles in the linear pile group, the BCR coefficient slightly decreases. The BCR coefficient of the 2×1(p) pile group is 3% higher than the BCR coefficient of the 3×1(p) pile group, and the BCR coefficient of the 2×1(v) pile group is 4% higher than the BCR coefficient of the 3×1(v) pile group.

The efficiency coefficient of the non-grouted pile group parallel to the slope is higher than that of the pile group perpendicular to the roof slope, and the efficiency coefficient decreases with an increase in the number of piles in the linear group. The efficiency coefficient of the pile groups without injection 2×1(p) and 2×1(v) are 0.89 and 0.89, respectively, and the efficiency coefficient of the 3×1(p) and 3×1(v) groups are 0.86 and 0.84, respectively. The efficiency coefficient of the post-injection pile groups does not depend on the pile group direction, and the efficiency coefficient of the pile groups parallel and perpendicular to the roof slope are approximately equal. The efficiency coefficient of the post-injection pile groups 2×1(p) and 2×1(v) are 0.92 and 0.93, respectively, and the efficiency coefficient of the 3×1(p) and 3×1(v) groups are 0.85 and 0.86, respectively.

Table 5. bearing capacity of pile group

		Pile group			
		2×1(p)	2×1(v)	3×1(p)	3×1(v)
Non-grout	Bearing capacity	11066	12296	15854	18223
	efficiency coefficient	0.87	0.89	0.84	0.86
	Tilting	0.0024	0.0001	0.0019	0.00095
Post Grout	Bearing capacity	16616	17613	22978	24927
	BCR	1.50	1.43	1.45	1.37
	efficiency coefficient	0.92	0.93	0.85	0.86
	Tilting	0.0013	0.00075	0.0013	0.0007

4. Conclusions

The results of this research can be summarized as follows

1-The tilting pile group in the post-grout pile groups is less than the tilting pile group in the non-grout pile group. This was observed in all pile diameters, all pile spacings, and all embedded lengths.

2-The effect of the post-grout process on increasing the bearing capacity of pile groups adjacent to the slope is greater than that of pile groups installed on a horizental ground.

3-The effect of the post-grout process on increasing the bearing capacity of pile groups linearly parallel to the slope crest is greater than that of pile groups perpendicular to the slope crest.

4-As the number of piles in a linear pile group increases, the effect of the post-grout process on increasing the bearing capacity of the pile group decreases.

5-Increasing the pile diameter leads to an increase in the effect of the post-grout process on the bearing capacity of the pile group.

6-With an increase in the embedded length of the pile, the effect of the post-grout process on increasing the bearing capacity of the pile group decreased.

7-The slope effect on reducing the bearing capacity in post-grout pile groups is less than in non-grout piles.