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Influence of single anchor rod in sheet pile with different water table in sandy and clay soil

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Abstract

Retaining walls are used to retain earth or water at different levels on both sides. The most useable and enduring sheet piles are constructed of steel and concrete. The most common form of sheet pile is a steel sheet pile because of its good resistance to high driving resistance. The different parameters affect the behavior of sheet pile such as the embedded depth, numbers of anchor rods used, positions of anchor rods, ground water table, flexural rigidity of sheet pile wall. Presence of water table behind or on front side of sheet pile impose lateral loads on sheet pile. The paper studied a case of using anchor rod in cantilever sheet piles with different water tables in sandy and clay soil backfill. Firstly, the classical and numerical results are compared in this paper. Some structural behaviors need to know for engineers to establish a sheet pile because of uncertainty of ground water table may come behind sheet pile or on front side of sheet pile wall. Regardless of the free height, friction angle, unit weight of sand and whatever the position of GWT exists, a certain anchor position causes certain percentage reductions of maximum bending moments and required embedded depths for different ground water conditions are studied for sandy soil backfills. Increase the depth of anchor's position causes more reduction of maximum bending moment, embedded depth of sheet pile and also to hold the same embedded length, lowering position of anchor rod resulted an increase of anchor forces developed in single anchor sheet pile in sandy soil. Some graphs are established showing the necessity to use anchor rod for sheet pile in clay soil when it goes beyond the threshold values.

Keywords: Sheet pile wall, anchor rod, water table, sandy soil, clay soil.

1. Introduction

Sheet pile walls are retaining walls constructed to retain earth, water or any other filling materials that are driven into the ground to provide earth retention and excavations support. They are broadly used as structural designing activities, for example, earth retaining structures, braced cuts, cofferdams, and continuous walls of waterfront structures (Grande et al., 2002; Krabbenhoft et al., 2005). Different types of materials such as timber, steel or reinforced concrete can be used as a sheet pile walls. Higher resistance is produced against the high stresses when steel sheet pile is driven into stiff soils. Sheet piles can function as temporary or permanent structures but are most often used in excavation projects. Temporary sheet piling structures are used to control or retain earth or water and before of permanent retaining work. They are divided according to their height; cantilever and anchored sheet pile. Generally, cantilever sheet pile walls used to restrain excavation when the depth of the excavation is small. The anchored sheet piles are recommended for walls of height exceed 6 m (Dina et al., 2018). If the depth of the excavation exceeds about 6 m, the anchored sheet pile walls are used (Das, 2016; Sabatini et al., 1999). By using anchor rods, the required penetration depth, maximum moment and cross section area of the sheet piles were decreased. Many researchers studied different types of retaining walls subjected to different loading conditions by using the finite element method (FEM). Dina and Safwat (2016) conducted an experimental and numerical study using PLAXIS program on two different systems of single and double anchored sheet pile walls subjected to loose fine sand backfill only and performed a comprehensive comparison between the experimental and numerical study.

A numerical parametric study conducted by Dina and Safwat (2018) on both systems of single and double anchored sheet piles subjected to sandy backfill of different soil types (loose, medium dense and dense sand) and evaluated the variation of maximum values of bending moments and anchor forces exerted in the sheet piles. They showed the different parameters which affected the behavior of sheet pile such as the embedded depth, positions of anchor rods and the sheet pile wall flexural rigidity.

Although retaining walls are used frequently on excavations and thus their design approaches and methods are deeply studied, its behavior in backfill construction is still not as much understood and predictable (Bilgin, 2010). Actually, the current design procedures are based on limit equilibrium approaches that make use of active and passive earth pressures which is related to the Mohr-Coulomb failure criterion (Hassani et al., 2016). Conventional assumptions and tools, such as the Rowe moment reduction curves used to calculate design moment, might not be valid in backfilling conditions since they are based on tests simulating walls in excavation conditions (Bilgin, 2010). Hassani (2016) included the classical design procedures in his study which are in common use today by most engineers involved in the design of sheet pile retaining structures and these methods have consistently provided successful retaining structures that have performed well in service.

It is a very important factor that a sheet pile can be subjected to ground water that may come behind or on the front side of the sheet pile. A sheet pile that is designed without considering water table can be unstable if ground water comes uncertainly behind or on the front side of sheet pile. Water imposes the lateral load on sheet pile which increases the maximum bending moment and required embedded depth of sheet pile. Ground water is the important consideration that influence the behavior of sheet pile. Sometimes the required depth becomes so high that cannot be provided practically or not be economical. In order to reduce depth and maximum bending moment, anchor should be used. Anchor rod should be such a position that gives lower values of maximum bending moment resulted in a decrease of embedded depth.

Numerical modelling has been developed over the years. Research has found that these numerical methods for the design of sheet pile walls are very useful (Bilgin, 2010). Many researchers studied the safety conditions, soil deformation, lateral earth pressure distribution and stress-strain analysis for cantilever sheet pile walls and anchored sheet pile walls using the finite element method (Bahrami et al., 2018; Cherubini, 2000; Dina et al., 2018; Finno et al., 2007). Researchers have made comparison between classical and numerical methods and they have found reliable results (Hassani et al., 2016). In this paper, the numerical analysis of anchored sheet pile walls was implemented by finite element program GEO5.

2. Methodology

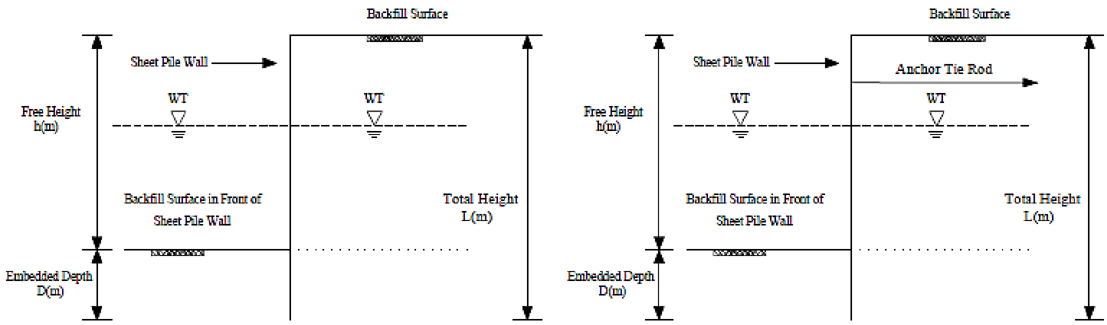


Fig. 1. Typical wall section of (a) cantilever and (b) single anchored sheet piles used in the analysis.

The geometry used in classical and numerical analysis is the cantilever and anchored steel sheet pile walls. Sheet pile wall behaviors are affected by some parameters such as backfill soil, position of anchor rod, ground water table (GWT). Three GWT conditions were used in this study such as “No GWT”, “GWT at both side” and “GWT behind sheet pile”. In this paper, three different positions of ground water table are taken such as 0.25h, 0.4h and o.5h in cantilever and single anchored sheet pile. 0.25h, 0.4h and 0.5h indicate the depth measured from backfill surface to the dredge level whereas h means free height shown in Figure 1. GWT behind sheet pile means that the water is found behind the structure only. Hence, there is no water acting on the front face of sheet pile. GWT at both sides means the water is assumed to be act at both sides simultaneously with same level. For the cases of anchored sheet pile wall, the positions of anchor rod 0.25h, 0.4h and o.5h are used. Each entire model has one soil layer either sand or clay backfill in Figure 1. The sand soil has no cohesion (c=0) and clay soil is considered to be purely cohesive (ϕ=0). Sand friction angle varies from 27^o to 45^o with varying unit weight 14 to18 KN/m^3 generally. According to Bowles’s foundation analysis and design, cohesion of very soft to hard cohesive soil varies from 0 to 4 kips/ft^2 and saturated unit weight varies from 100 to 140 lb/ft^3 for SPT penetration values from 0 to 32 blows/ft. Firstly, classical and numerical parametric studies were performed on single anchored and cantilever sheet pile systems using sandy and clay soil backfill respectively to see the variations between classical and numerical results. Then other studies are done by numerical analysis. Secondly, the maximum bending moment and embedded depth reductions are determined considering ground water table (GWT) for different positions of an anchor rod in sandy soil and thirdly the effects of anchor position with varying surcharge loads are studied on the behavior of sheet pile when it is penetrating in sandy soil. Lastly, some graphs are established showing the necessity to use anchor rod for sheet pile in clay soil when it goes beyond a value. Bowles (1996) proposed the horizontal displacements at the upper part of the wall which are sufficient to produce the active state of pressure given in Table 1 and the upper horizontal displacements obtained for sheet pile were compared to the values of Table 1.

Table 1
Horizontal wall movement required to achieve active state

Soil type and condition	Amount of translation of sheet pile wall
Cohesionless, Dense	0.001h-0.002h
Cohesionless, Loose	0.002h-0.004h

2.1 Numerical analysis

In this paper, the numerical analysis of anchored sheet pile walls is implemented by finite element program GEO5. It is designed to solve various geotechnical problems and can be used to model different element types; such as different retaining wall types, anchors to support the retaining wall, various types of loads. Classical and numerical analysis are implemented by free earth support method for single anchored sheet piles. The steel sheet pile VL-503k is used in numerical analysis. The numerical model provides more details for the behavior of both soil, structure and design outputs. By default, Finite element program assumes 6-node triangular elements with mesh smoothing.

2.2 Classical method

Single anchored and cantilever sheet pile walls are designed by the classical method in case of sandy and clay soi backfill respectively which processes are presented by Figure 2 and Figure 3. Rankine's theory is used to determine coefficients and the earth pressure acting on sheet pile wall. The classical methods based on the limit state equilibrium take into account the internal stability and external stability of the sheet pile wall (Moamen, 2020). The current limit state design method is most commonly used in the United Kingdom (UK) which is known as the UK method, described by Padfield and Mair (1984). In the United States (US), the USA method is the most commonly used limit state design method, described by Bowles (1996). Suggesting a rectilinear pressure distribution simplifies the net pressure distribution along the sheet pile wall (Hassani et al., 2016).

2.2.1 Designing single anchored sheet pile based on classical method

The classical method for designing sheet pile without surcharge conditions are shown in Figure 2. The process of calculating the parameters is presented in the following for without surcharge condition with resort of U.S. Army Corps of Engineers (1994) and Das (2016). Rankine’s active and passive pressure coefficients:

$$K_a = tan^2\left(45 - \frac{\emptyset}{2}\right) \tag{1}$$

$$K_p = tan^2(45 + \frac{\emptyset}{2}) \tag{2}$$

$$\gamma' = \gamma_{sat} - \gamma_w \tag{3}$$

$$P_1 = \gamma L_1 K_a \tag{4}$$

$$P_2 = (\gamma L_1 + \gamma'^{L_2})K_a \tag{5}$$

$$L_3 = \frac{P_2}{\gamma'(K_p - K_a)} \tag{6}$$

$$P_a = 0.5 * P_1 * L_1 + P_1 * L_1 + 0.5 * (P_2 - P_1) * L_2 \tag{7}$$

$$\frac{\gamma'(K_p - K_a)}{3} {L_4}^3 - \frac{\gamma'\left(K_p - K_a\right)(h + L_3)}{2} {L_4}^2 - P_a Y_1 = 0\,; h = l + L_2 \tag{8}$$

$$P_3 = \gamma'\left(K_p - K_a\right)L_4 \tag{9}$$

$$P_P = 0.5 * P_3 * L_4 \tag{10}$$

The theoretical embedded depth (D), the actual embedded depth (D_{act}), anchor force (F_a) and maximum moment are calculated:

$$D_{theoretical} = L_4 + L_3 \tag{11}$$

$$D_{actual} = 1.3 D_{theoretical} \tag{12}$$

$$L_{required\ length\ of\ sheet\ pile} = H + D_{actual} \tag{13}$$

$$F_a = P_a - P_P \tag{14}$$

$$0.5\sigma_1' L_1 - F + \sigma_1{}'(Z - L_1) + 0.5K_a\gamma'(Z - L_1)^2 = 0\,;\; L_1 + L_2 < Z < L_1 \tag{15}$$

$$x = Z - L_1 \tag{16}$$

$$M_{max} = 0.5\sigma_1' L_1 \left(x + \frac{L_1}{3}\right) - F(x + l_1) + \sigma_1' x \left(\frac{x}{2}\right) + 0.5K_a\gamma'^{x^2}\left(\frac{x}{3}\right) \tag{17}$$

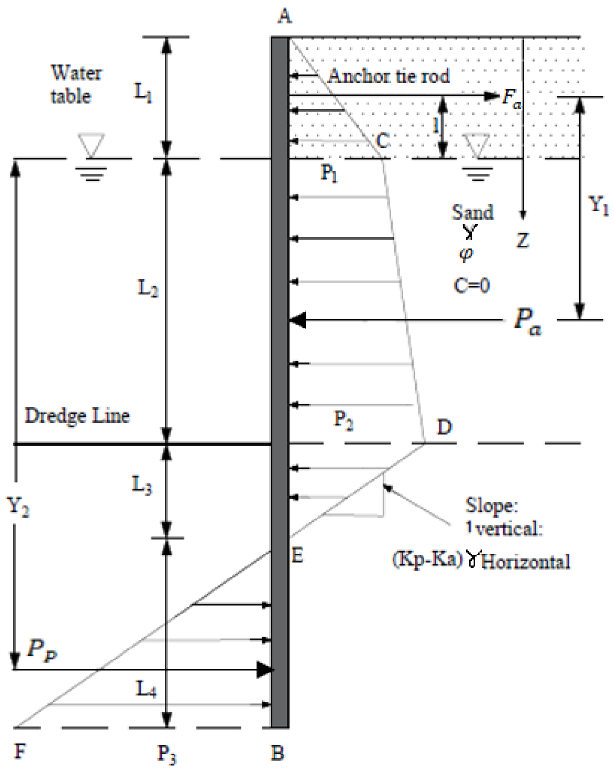


Fig. 2. Design of anchored sheet pile wall penetrating in sand without surcharge condition.

2.2.2 Designing cantilever sheet pile in clay based on classical method

H is the height of wall above dredge line and D is the depth of embedment. The soil is considered to be purely cohesive ($\varphi = 0$) both above and below the dredge line. process of calculating the parameters is presented in the following for without surcharge condition with resort of U.S. Army Corps of Engineers (1994) and Das (2016).

At any depth Z_0 below the surface of fill, the pressure intensity is zero

$$Z_0 = 2c/\gamma \tag{18}$$

$$P_{A(right)} = \gamma H - 2c\ (for\ \varphi = 0) \tag{19}$$

$$P_{B(left)} = 4c - q = 2q_u - \gamma H \tag{20}$$

$$P_{B(rigth)} = 4c + q = 2q_u + \gamma H \tag{21}$$

Where c is cohesion and q_u is unconfined compressive strength equal to $2c$

$$P = 0.5 * {Z_0}^2 * \frac{\gamma z - 2c}{H - Z_0} \tag{22}$$

$P_a = 0.5 * (\gamma H - 2c) * (H - Z_0)$ which acts at $y' = (H - Z_0)/3$ from dredge level (23)

$$x = \frac{P_a - P}{4c - \gamma H} \tag{24}$$

$$h = \frac{D(4c - \gamma H) - P_a}{4c} \tag{25}$$

$${D_{the}}^2(4c - \gamma H) - 2D_{the}P_a - \frac{P_a(12cy' + P_a)}{2c + \gamma H} = 0 \tag{26}$$

After getting theoretical embedded depth D_{the} , actual embedded depth D_{actual} is to be calculated

$$D_{actual} = 1.3D_{theoretical} \tag{27}$$

$$L_{required\ length\ of\ sheet\ pile} = H + D_{actual} \tag{28}$$

$$M_{max} = P_a * (y' + x) - (4c - \gamma H) * 0.5 * x^2 - P * \left(L_1 + L_2 + x - \left(\frac{h}{3}\right)\right) \tag{29}$$

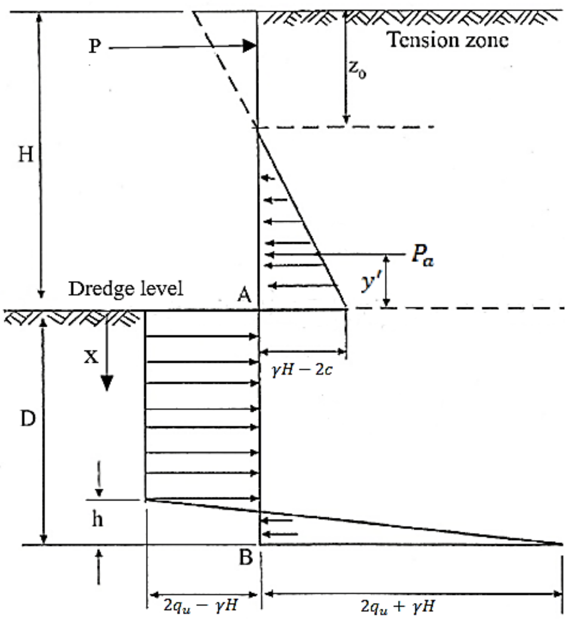


Fig. 3. Design of anchored sheet pile wall penetrating in sand without and with surcharge condition.

3. Results and discussion

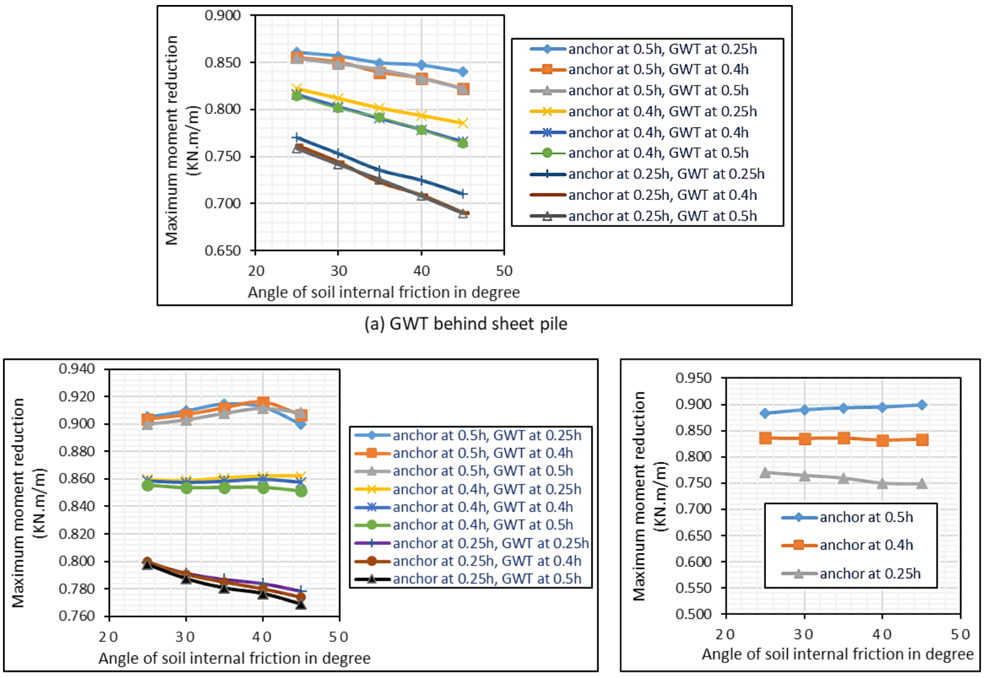
3.1 Comparison between classical and numerical results

The results obtained by classical method were compared with the results obtained by numerical analysis for a single anchored and cantilever sheet pile penetrated in sandy and clay soil respectively. A study was done on a single anchored sheet pile of 9 m free height penetrating in sandy soil backfill where unit wight and saturated unit weight were taken 18 KN/m^3 and 20 KN/m^3 respectively with 40˚ friction angle (c=0). Anchor rod and GWT behind sheet pile were set at 2.25 m and 3.6 m below backfill surface respectively. The obtained results of maximum bending moment, required embedded depth of sheet pile and anchor force are 493 KN.m/m, 3.28 m and 162 KN/m respectively by numerical analysis in where classical method also give the same values. Another study was done on a cantilever sheet pile of a 5 m free height penetrating in clay soil backfill where unit wight was taken 17

KN/m^3 with 25 KN/m^2 cohesion ($\varphi = 0$). Classical method and numerical analysis give the same results and the obtained results are 131 KN.m/m for maximum bending moment and 9.7 m for required embedded length of sheet pile.

3.2 Reduction of maximum bending moment and embedded depth in sand

Sand friction angle varies from 27º to 45º with varying unit weight 14 to18 KN/m^3 generally. Firstly, to avoid complexity the dry unit weight (γ_{dry}) and saturated unit weight (γ_{sat}) of the sand were taken 18 KN/m^3 and 20 KN/m^3 respectively with varying friction angle (φ) to establish Figure 4 and Figure 5. It is shown in Figure 4 that the values of maximum moment reductions are close to each other with the variation of the friction angle for a certain position of anchor rod in sand. Also, for a certain anchor position, the ranges of maximum bending moment reduction are almost same for all three positions of GWT behind sheet pile or GWT at both sides. When the sheet pile subjected to GWT behind sheet pile, using of anchor rod at 0.5h yielded on average 84% reduction of maximum bending moment. Lowering position of anchor rod causes more reduction of the maximum bending moment. The values of maximum moment reduction are 79% and 73% at the positions of anchor rod 0.4h and 0.25h respectively for GWT behind sheet pile wall condition. Similarly, the on average reduction of maximum bending moments are 90%, 85% and 78% when the anchor rods are set at 0.5h, 0.4h and 0.25h respectively for GWT at both sides of the sheet pile wall. If there is no chance that sheet pile can be subjected to GWT from behind or on front side, the moment induced in sheet pile wall yielded about 89% reduction when anchor rod is set at 0.5h, 83% reduction when anchor rod at 0.4h, 75% when anchor rod at 0.25h.



(b) GWT at both sides (c) No GWT

Fig. 4. Maximum bending moment reductions when using single anchor rod for different GWT conditions.

Similarly, Figure 5 represents that the values of embedded depth reductions are not varied much with the variation of the friction angle for a certain position of anchor rod in sandy soil. Also, for a certain anchor position, the ranges of embedded depth reduction are almost same for all three positions of GWT behind sheet pile or GWT at both sides. When the sheet pile is subjected to GWT behind sheet pile, using of anchor rod at 0.5h, 0.4h and 0.25h yielded on average 65%, 63% and 61% reduction of embedded depth respectively. Lowering position of anchor rod, higher reduction of the embedded depth induced in sheet pile. Similarly, the on average reduction of embedded depths are 72%, 67% and 65% when the anchor rods are set at 0.5h, 0.4h and 0.25h respectively for GWT at both side conditions. When no GWT condition exists, the embedded depth induced in sheet pile wall yielded about on average 71% reduction when anchor is set at 0.5h, 68% reduction when anchor at 0.4h, 66% when anchor at 0.25h. For a certain position of anchor rod and GWT, reductions of maximum bending moment and embedded depth are yielded same percentages with varying free height of sheet pile. As it is seen in Table 1 that the percentage reduction of maximum bending moment is 81% when anchor is set at 0.4h for the position of GWT behind sheet pile at 0.25h and this percentage remains same for whatever free heights are used for design purpose of sheet pile. So regardless of free height, Table 2 shows the results which are close to the average results of Figure 4 and Figure 5. Table 3 illustrates the reduction of the maximum bending moment and embedded depth with the variation of unit weight of sand when friction angle, saturated unit weight and free height remain unchanged. The reductions remain same with the variation of unit weight of sand for a certain anchor position.

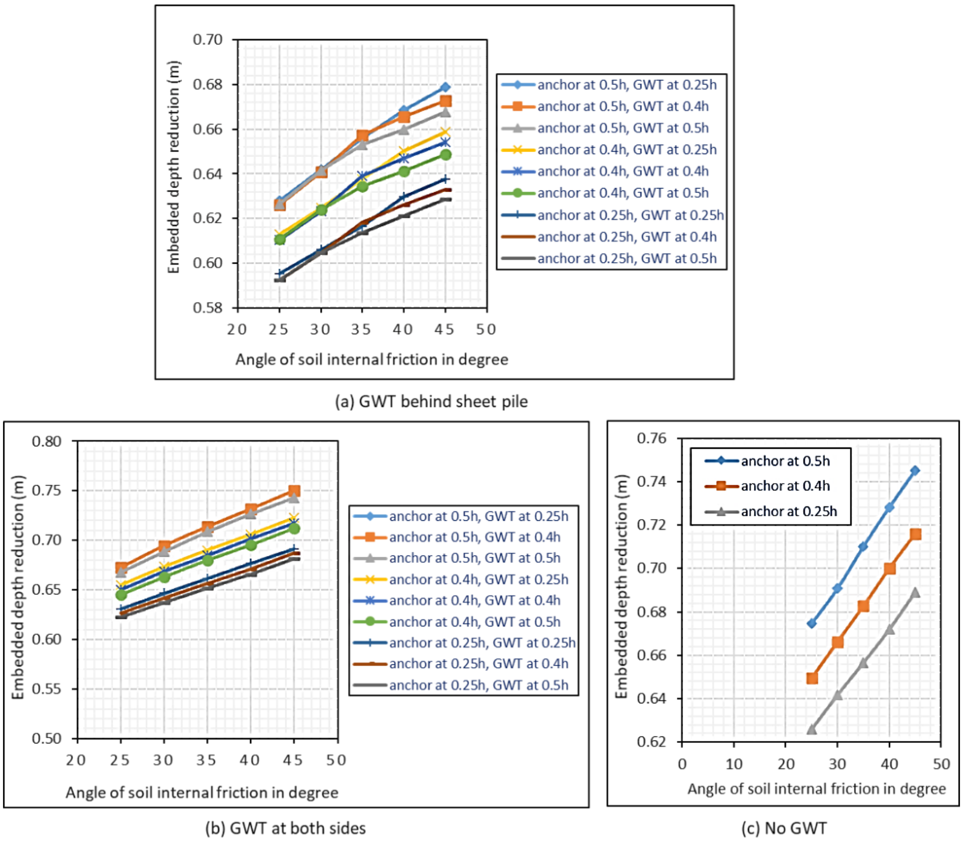


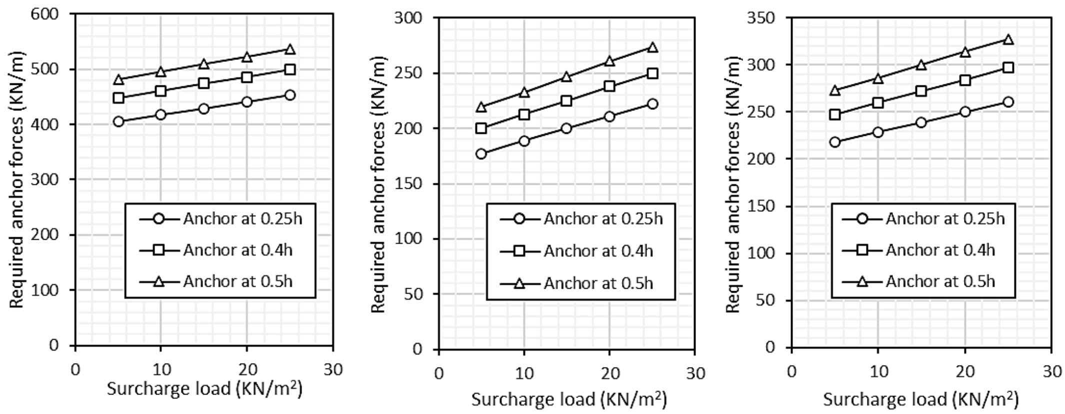
Fig. 5. Embedded length reductions when using single anchor rod for different GWT conditions.

Firstly, a study was done for a certain unit weight and saturated unit weight with varying friction angle. Then it is checked whether the percentages of maximum bending moments and embedded depths are changed for a certain friction angle along with the variation of free height or unit weight of sand. Finally, it can be said that regardless of free height, friction angle, unit weight of sand and whatever the position of GWT exists, the percentage reduction of maximum bending moment or required embedded depth gives a certain value at a certain anchor position for any type of sand (loose, medium and dense sand).

Table 2
Maximum bending moment and embedded depth reduction with varying free height of sheet pile

Free Height (m)	Maximum moment induced (KN.m/m)			Maximum moment reduction (KN.m/m)		Embedded length induced (m)			Embedded length reduction (m)	
	without using anchor	Using anchor rod at 0.25h	Using anchor rod at 0.4h	Using anchor rod at 0.25h	Using anchor rod at 0.4h	without using anchor	Using anchor rod at 0.25h	Using anchor rod at 0.4h	Using anchor rod at 0.25h	Using anchor rod at 0.4h
30º friction angle, γ =18 KN/m^3, γ_{sat} = 20KN/m^3										
GWT behind sheet pile at 0.25h										
9	4221	1041	795	0.75	0.81	15.08	5.91	5.63	0.61	0.63
8	2965	730	559	0.75	0.81	13.41	5.26	5	0.61	0.63
7	1986	490	374	0.75	0.81	11.74	4.6	4.38	0.61	0.63
6	1251	308	236	0.75	0.81	10.06	3.94	3.75	0.61	0.63
5	724	179	137	0.75	0.81	8.39	3.29	3.13	0.61	0.63
4	371	92	70	0.75	0.81	6.71	2.63	2.5	0.61	0.63
3	157	39	30	0.75	0.81	5.03	1.97	1.88	0.61	0.63
GWT at both side at 0.25h										
9	1393	291	197	0.79	0.86	10.89	3.85	3.56	0.65	0.67
8	978	205	135	0.79	0.86	9.67	3.45	3.25	0.64	0.66
7	655	137	92	0.79	0.86	8.46	3	2.77	0.65	0.67
6	413	87	58	0.79	0.86	7.26	2.57	2.37	0.65	0.67
5	239	50	34	0.79	0.86	6.05	2.14	1.98	0.65	0.67
4	122	26	17	0.79	0.86	4.83	1.71	1.58	0.65	0.67
3	52	11	7	0.79	0.87	3.64	1.28	1.18	0.65	0.68
No GWT										
9	1635	385	269	0.76	0.84	9.38	3.36	3.13	0.64	0.67
8	1149	270	189	0.77	0.84	8.34	2.99	2.78	0.64	0.67
7	770	181	127	0.76	0.84	7.31	2.62	2.43	0.64	0.67
6	485	114	80	0.76	0.84	6.26	2.24	2.05	0.64	0.67
5	281	66	46	0.77	0.84	5.22	1.87	1.74	0.64	0.67
4	144	34	24	0.76	0.83	4.18	1.5	1.39	0.64	0.67
3	61	14.23	10	0.77	0.84	3.13	1.12	1.04	0.64	0.67

3.3 Effects of anchor position with surcharge load in sand



(a) GWT behind sheet pile at 0.25h (b) GWT at both sides at 0.25h (c) No GWT

Fig. 6. Effect on anchor forces induced in single anchored sheet for lowering the position of anchor rod pile with surcharge load in sand.

Table 3
Maximum bending moment and embedded depth reduction with varying unit weight of sand

30º friction angle, γ_{sat} =KN/m^3, Free height 9 m						
GWT behind sheet pile at 0.25h						
Unit weight of sand soil (KN/m^3)	Maximum bending moment induced (KN.m/m)		Maximum bending moment reduction (KN.m/m)	Embedded length induced (m)		Embedded length reduction (m)
	without using anchor	Using anchor rod at 0.25h		without using anchor	Using anchor rod at 0.25h	
17	4370	1093	0.75	15.65	6.1	0.61
18	4221	1041	0.75	15.08	5.91	0.61
19	4100	1009	0.75	14.6	5.69	0.61
GWT at both side at 0.25h						
17	1329	279	0.79	10.7	3.74	0.65
18	1393	291	0.79	10.89	3.85	0.65
19	1458	306	0.79	11.06	3.87	0.65
No GWT						
17	1543	362	0.76	9.4	3.35	0.64
18	1635	385	0.76	9.38	3.36	0.64
19	1725	406	0.76	9.37	3.37	0.64

Figure 6 represents the results of anchor forces for a single anchored sheet pile wall in case of sandy soil. With the increases of the surcharge load, the required anchor force increases linearly to hold the same embedded length of sheet pile wall for a certain anchor position. In order to hold the same embedded length, lowering position of anchor rod resulted an increase of anchor forces developed in a single anchor sheet pile for any level of GWT either on both sides or behind of sheet pile and “No GWT” condition. It also indicates that the required anchor force is higher for the condition of GWT acted behind sheet pile than the condition of GWT acted at both sides for same height of water table.

3.4 The necessity to use anchor rod for cantilever sheet pile in clay soil

The graphs of maximum bending moment against $\frac{q'+u_1-u_2}{4*c}$ are established for the cantilever sheet pile wall in case of clay soil. Threshold values were found out and above which the maximum bending moment increases significantly in cantilever sheet pile wall. The ratios are developed in terms of effective stress at dredge level in KN/m^2 (q'), cohesion of clay in KN/m^2 (c) for $(\varphi = 0)$ condition, GWT behind sheet pile in KN/m^2 (u_1) and GWT on front side of sheet pile in KN/m^2 (u_2). GWT behind sheet pile means that there is no water acting on the front face of the sheet pile. So GWT in front of sheet pile in KN/m^2 (u_2) becomes zero. GWT at both sides means the water is acting at both sides at same level. That’s why (u_1) and (u_2) have a value. For no GWT condition, the value of (u_1) and (u_2) are zero and as there is no water present behind sheet pile wall, effective stress at dredge level in KN/m^2 (q') is equal to total stress at dredge level (q).

When a cantilever sheet pile is induced by higher bending moment requires higher embedded depth to make it stable in soil. Higher embedded depths are not provided practically and not be economical also. By using anchor rods, the required higher penetration depth of the sheet pile can be decreased much which make possible to withstand the sheet pile in soil. the obtained threshold values are around 0.77, 0.97 and 1 for “GWT behind sheet pile”, “GWT at both side” and “No GWT” conditions respectively. After Reaching these values, it becomes necessary to use of anchor rod for sheet piles in clay soil. It is a very important factor to be considered for the design of sheet piles in clay soil.

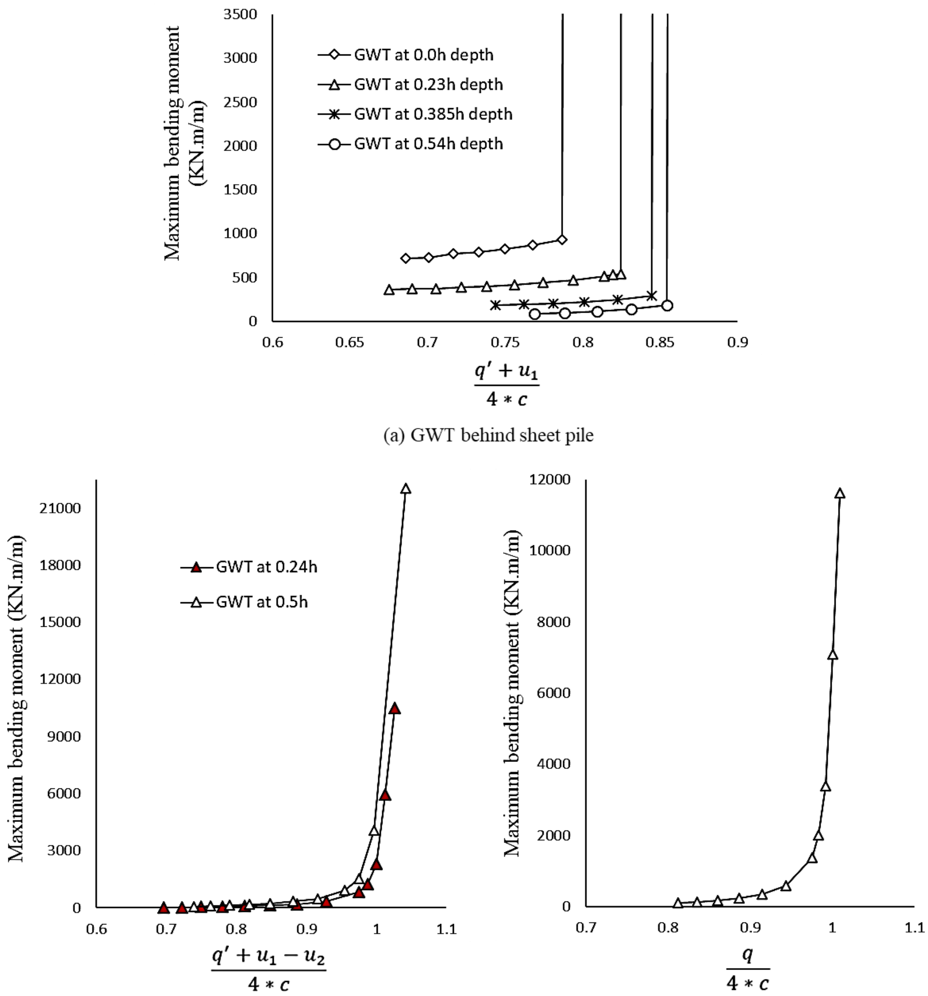


Fig. 7. Sudden large increases of maximum bending moments induced in cantilever sheet pile in terms of q', C_u, u_1, u_2 in clay.

4. Conclusions

The following conclusions are drawn from this study:

- Results obtained by classical method were found similar to the results obtained by numerical analysis for single anchored and cantilever sheet pile in case of sandy and clay soil respectively.
- Regardless of free height, friction angle and unit weight of sand and whatever the position of GWT exists in any type of sand (loose, medium and dense sand), when the sheet pile is subjected to GWT behind sheet pile, using of anchor rods at 0.5h, 0.4h, 0.25h yielded on average 84%, 79% and 73% reduction of maximum bending moment respectively. when anchor rods are set at 0.5h, 0.4h and 0.25h, the maximum moment induced in sheet pile wall yielded on average 90%, 85%, 78% reduction for GWT at both sides condition. When no GWT condition exists, the reductions of maximum bending moment are 89%, 83% and 75% for the positions of anchor rod 0.25h, 0.4h and 0.5h respectively.
- Regardless of free height, friction angle and unit weight of sand and whatever the position of GWT exists in any type of sand (loose, medium and dense sand), the reduction of embedded depths are on average 65%, 63% and 61% for the positions of anchor 0.5h,

0.4h and 0.25h respectively when sheet pile is subjected to GWT behind sheet pile. The on average reduction of embedded depths are 72%, 67% and 65% when the anchor rods are set at 0.5h, 0.4h and 0.25h respectively for GWT at both sides condition. When no GWT condition exists, the embedded depth induced in sheet pile wall yielded about 71% reduction when anchor is set at 0.5h, 68% reduction when anchor at 0.4h, 66% when anchor at 0.25h.

- It is seen from Point 2 and Point 3 that lowering position of anchor rod, higher reduction of maximum bending moment and embedded depth induced in sheet pile.
- With the increases of the surcharge load, the required anchor force increases linearly to hold the same embedded length of sheet pile wall at a certain anchor position in sand. In order to hold the same embedded length, lowering position of anchor rod resulted an increase of anchor forces developed in a single anchor sheet pile.
- Threshold values were found out and above which the maximum bending moment increases significantly in cantilever sheet pile wall. the values are around 0.77, 0.97 and 1 for "GWT behind sheet pile", "GWT at both side" and "No GWT" conditions respectively. After Reaching these values, it becomes necessary to use of anchor rod for sheet pile in case of clay soil.

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