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Comparison of Design Requirements for Non-Anchored and Anchored Sheet Piles as Retaining Wall in a Basement

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Abstract

The construction of a 9-meter deep basement on clay soil with a soft consistency necessitates the use of a sheet pile for soil retention. Selected due to the soft soil conditions and a high groundwater level at the site, the sheet pile effectively addresses these challenges. The design calculations for the sheet pile, based on the Terzaghi concept, incorporated both active and passive earth pressures determined using the Rankine method. Analysis revealed a lateral force of 19,624 t/m² at a depth of 9 meters. The resulting design specifies a 10-meter embedded concrete pile without anchors, requiring a total sheet pile length of 19 meters. The chosen sheet pile type is W-600 A-1000. Alternatively, with anchors, the design calls for a 4-meter depth using type W-325A-1000 concrete sheet pile, with one anchor installed at a depth of 3 meters. The anchor's tensile strength is 5.46 tonnes, resisting a force of 113.817 Tm with a diameter of 5 cm. Modelling analysis showed that unanchored sheet piles have a safety factor of 0.770 and exhibit lateral deformation of 0.00803 meters. Conversely, the addition of anchors enhances the safety factor to 1.146 and increases lateral deformation to 0.0195 meters, indicating that anchors significantly improve safety and reduce deformation.

1. Introduction

The construction of a basement is carried out by excavating soil. During the excavation process, a soil retaining structure is necessary to keep the soil stable even when excavated. The soil retaining structure for excavation can be an anchored sheet pile, an unanchored sheet pile, or a secant pile. The choice of type will be based on the soil type, load, and stability of the retaining wall.

The soil conditions for the basement construction, based on borehole data within 40 meters, indicate that the dominant soil type at the depth of construction is clay. The consistency of the clay at a depth of 9 meters, corresponding to the planned depth, is soft. This soft clay contains a high water content. During the excavation process, the high groundwater level is so forceful that it requires anticipation of soil shrinkage. The construction of the retaining wall must consider the soil conditions to ensure a stable design.

Deep excavations relieve stress, which results in excessive lateral soil movements. They will cause additional bending moments and deflections [15]. A soil retaining wall is a structure designed and built to withstand lateral (horizontal) soil pressures when there is a change in soil elevation that exceeds the at-rest angle in the soil. A type of retaining wall that can be used in high groundwater conditions and whose installation is not hindered by water presence is the sheet pile. The fact that when sheet pile are pressed, there is no negative affect on the encompassing building [11]. As they are embedded in soil, sheet piles are structural tools meant to resist horizontal stresses and serve as retaining system as well [14].

A sheet pile wall is a relatively thin vertical wall that serves not only to retain soil but also to prevent water from entering the excavation pit. If the soil depth is shallow, a cantilever sheet pile may be sufficient. For deeper excavations, an anchored sheet pile can be used. Anchored sheet pile walls, or sheet piles installed with the help of anchors placed at the top, offer the advantage of enhanced soil resistance anchored into the ground. The anchored sheet pile wall is quite economical for greater depths and high surcharge load taken with lesser wall movement, besides very simple and rapid implementataion [12]. The number of anchors adjusts according to the height of the soil being retained; for heights greater than 11 meters, at least two anchors are required.

The trial-and-error process were done with trial configuration is controlled against different stability criteria of the sheet pile design [13]. The design, once calculated, must then be modeled using software to determine the overall structural safety factor. The purpose of the soil retaining design in this study is to compare the sheet pile designs before and after the installation of anchors. The comparison analyzes changes in the safety factor and the reduction in lateral deformation, thereby ensuring that the use of sheet piles as retaining walls in basement construction with soft soil and high groundwater conditions is safer.

2. Methodology

Lateral Earth Pressure

The Rankine theory states that the lateral stress occurring on a soil retaining wall involves no adhesion or friction between the wall and the soil (friction is so minimal it is disregarded). Lateral pressure is limited to vertical walls at 90°. The resultant force is parallel to the surface of the backfill. Figure 1, Equation 1 is used to calculate the active earth pressure.

Passive earth pressure occurs when the pressure acting causes the wall to move toward the retained soil. Figure 2 and Equation 2 are used to calculate the stress due to passive earth pressure.

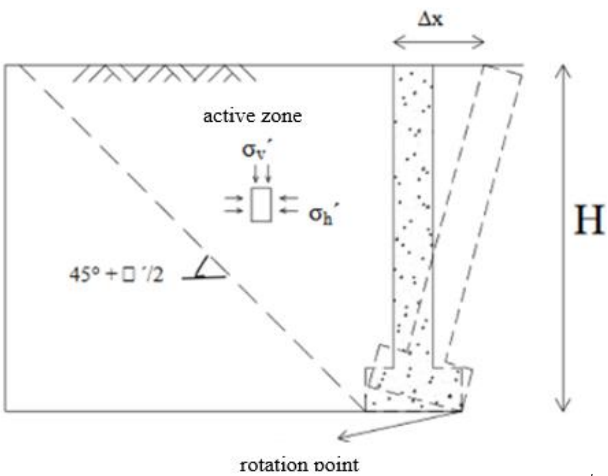

Figure 1. Active Earth Pressure $\sigma'_{ha} = \sigma'_v \times K_a - 2c'\sqrt{K_a}$ …(1)

Where:

- σ'_{ha}: active lateral pressure
- σ'_v: effective soil pressure
- c': soil cohesion
- φ': soil friction angle
- K_a: coefficient of active earth pressure, $K_a = \tan^2(45 - \varphi'/2)$

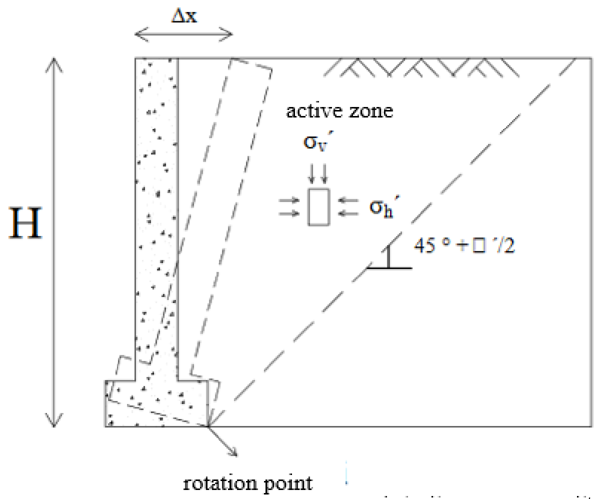

Figure 2. Passive Earth Pressure σ'hp = σ'v × Kp + 2c' √(Kp) …(2)

Where:

- σ'hp: passive lateral pressure
- σ'v: effective soil pressure
- c': soil cohesion
- φ': soil friction angle
- Kp: coefficient of passive earth pressure, Kp = tan² (45 + φ'/2)

Sheet pile design, the steps involved in the sheet pile design are as follows:

1. Calculate the magnitudes of active and passive stresses according to the planned depth.
2. Determine the depth and length of the sheet pile needed by calculating the total moment caused by active and passive stresses.
3. The concrete sheet pile profile will be adjusted according to the profile that will be applied in the appendix using Equations 3 and 4. The value of x is the same as the determination in point 2, with the condition d being changed to x.
   dΣM_total/dx …(3) W = M_total/σ_ij_in …(4)
4. Calculate the force (T') resisted by the anchor by first calculating the required force in a balanced condition using Equations 5 and 6. ΣP_active –(ΣP_passive + T) = 0 …(5) T' = T × S …(6)
   Where:
   - T': force resisted by the anchor
   - T: force required in a balanced condition
   - S: distance of the anchor (m)

After determining T', search for σ_anchor.

1. If the value h ≤ H/3, then it is considered that the anchor board height = H, and it includes the type of anchor block that extends near the surface of the soil, such that the passive and active soil pressures acting on the anchor block are as high as H.
2. The location of the anchor must be in a stable soil zone. The anchor block is located below the line drawn from the bottom end of the sheet pile, making an angle φ relative to the horizontal.

The methodology employed in this research consists of several detailed steps, designed to comprehensively assess and analyze the structural and safety aspects of sheet pile installations in a basement excavation of 9 meters depth, according to soil data from borehole BH1:

1. **Analysis of Horizontal Stress**: This step involves examining the magnitude of horizontal stresses acting within the basement excavation at a depth of 9 meters, utilizing soil data gathered from borehole BH1. This analysis helps in understanding the dynamic interactions between soil pressures and the retaining structures.

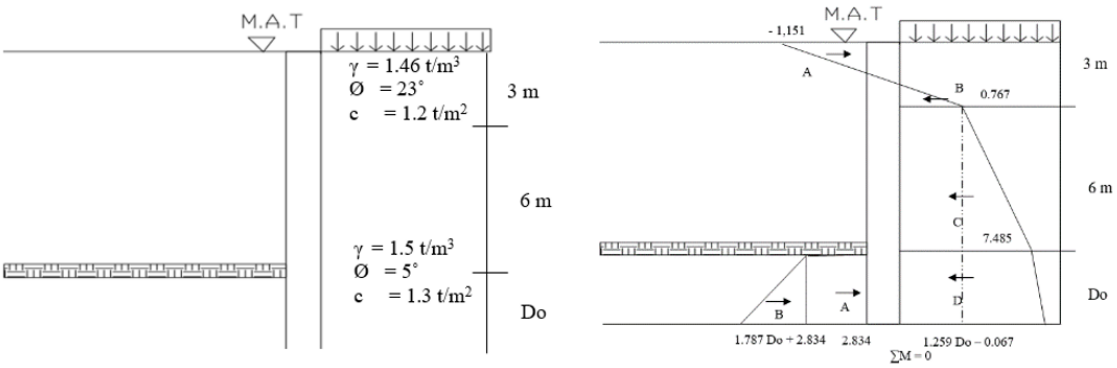

Figure 3. Soil Conditions and Diagram Showing Distribution of Lateral Stress at 9 m Depth
$Ka1 = \tan^2 (45 - (23^\circ)/2) = 0.438$; $Ka2 = \tan^2 (45 - (5^\circ)/2) = 0.839$; $Kp = \tan^2 (45 + (5^\circ)/2) = 1.191$

2. **Calculation of Unreinforced Sheet Pile Requirements**: Here, the focus is on determining the necessary specifications and dimensions of sheet piles that do not incorporate any reinforcements. This includes evaluating the appropriate types and sizes of sheet piles needed to withstand the calculated soil pressures without additional support structures.

3. **Calculation of Reinforced Sheet Pile Depth**: This involves assessing the requirements for sheet piles that include reinforcements, such as anchors. The calculations aim to determine the optimal depth and type of anchors needed to enhance the stability and strength of the sheet pile against lateral earth pressures.

4. **Safety and Lateral Deformation Analysis**: In this crucial phase, the safety factors and the extent of lateral deformation for each type of sheet pile (reinforced and unreinforced) are analyzed. This includes an in-depth review of how these parameters change with the introduction of reinforcements like anchors. The outcomes of this analysis are critical in understanding the structural integrity and effectiveness of the proposed soil retaining solutions under various stress conditions.

Each step of this methodology not only aims to assess the current capabilities of the sheet piling systems but also seeks to optimize the design and installation processes to enhance safety and reduce potential deformations in the context of the specific soil conditions found at the excavation site. This comprehensive approach ensures that all aspects of the construction are meticulously planned and executed, leading to more reliable and effective earth-retaining solutions.

3. Results

The analysis of soil stresses for an excavation reaching 9 meters in depth involves calculating both active and passive earth pressures, as illustrated in Figure 6. This calculation is based on the values of the coefficients of active (Ka) and passive (Kp) earth pressure, determined for each soil layer from borehole data (BH1). The loads considered in these calculations include a highway load of $q = 10$ kN/m² and the inherent weight of the soil itself.

Design of Unanchored Sheet Pile

By using the calculations illustrated in Figure 6, Table 1, and Table 2, the design for unanchored sheet piles begins by calculating the required depth (D). Once the depth of the sheet pile is determined, the next step is to select the appropriate sheet pile profile. The total moments are equated as follows:

Table 1. Calculation Results for Active Force and Active Moment

Point	(Pa) t/m²	Distance (m)	Active Moment (tm)
1	-0.921	((2/3 x 1.6) + 1.4 + 6 + Do)	-7.797 - 0.921 Do
2	0.537	((1/3 x 1.4) + 6 + Do)	3.472 + 0.537 Do
3	24.756	2	49.512
4	3.709 Do + 0.629 Do²	(0.333 Do)	1.235 Do² + 0.209 Do³

Table 2. Calculation Results for Passive Force and Passive Moment

Point	(Pp) t/m²	Distance (m)	Passive Moment (tm)
1			
2			
3	2.834 Do	0.333 Do	$0.787\ Do^2$
4	$0.894\ Do^2 + 1.417\ Do$	(0.333 Do)	$0.298\ Do^3 + 0.472\ Do^2$

$\Sigma MA = 0$
$\Sigma M\_active – \Sigma M\_passive = 0$
$\Sigma M\_Total = (0.209\ Do^3 + 1.235\ Do^2 – 0.384Do + 49.512) – (0.298\ Do^3 + 1.259\ Do^2)$
$= -0.089Do^3 - 0.024Do^2 – 0.384\ Do + 49.512$

In Points 1 and 2, the soil belongs to layer 1, while Soil 3 and Soil 4 are categorized under layer 2.

The selected depth D is approximately 7.963 meters, rounded to 8 meters, satisfying the required conditions. Following Hardiyatmo (2015), the penetration depth of the sheet pile is multiplied by a safety factor (1.2 - 1.4), thus D = 1.3 x 8 = 10.4 meters, approximately 10 meters. Therefore, the total required length of the sheet pile becomes 19 meters (9 + 10 meters). To determine the sheet pile profile, the moment equation yields D = 1.107:

$\Sigma M\_Total = -0.089(1.107)^3 – 0.024(1.107)^2 – 0.384(1.107) + 49.512 = 47.85$ ton.m

The next step involves selecting the appropriate sheet pile profile using the formula:

$W = 47.85/2310 = 0.0207\ m^3 = 2070\ cm^3$

Based on JIS A 5354, for a sheet pile length of 19 meters, a concrete sheet pile of type W-600A-1000 is necessary, with a section modulus of 25330 cm³. The comparison between the calculated and required section modulus is as follows:

$W = 25530\ cm^3 > 2070\ cm^3$ …………. OK.

This meticulous approach ensures that the design of the unanchored sheet pile is robust, capable of withstanding the calculated pressures, and adheres to safety standards.

Anchored Sheet Pile Design
The design of anchored sheet piles focuses on the strategic placement of anchors to enhance the stability and strength of the sheet pile structure, particularly beneficial in soft clay soils prone to high moisture and cohesion. For this project, the anchors are positioned at a depth of 3.5 meters, given the characteristics of the clay soil at the site, which aids in increasing the anchor's hold and effectiveness. This placement is crucial because the excavation depth for the sheet pile is 9 meters, and for excavations over 6 meters deep, the installation of at least one anchor is recommended to reinforce the structure.

Anchor Calculation Details:
- Depth (h) of anchor installation: 3.5 meters
- Due to the square shape of the planned anchor, the ultimate pullout resistance (Pu) is calculated with the formula:
  - $(H/h)CRS$=4.7+2.9×10−3≤7$(H/h)CRS$=4.7+2.9×10−3≤7
  - =4.7029≤7=4.7029≤7 (acceptable)

Calculation of Ultimate Pullout Resistance (Pu):
- The formula used to determine $PuPu$ simplifies the relationship between height and pullout resistance. It is expressed as:
  $(Hh)/(Hh)CRS(Puc\times Bh)/(7.425+1.575\times(hB))$

$=0.41+0.59\times(Hh)/(Hh)CRS(cPu\times Bh)/(7.425+1.575\times(Bh))(hH)/(hH)CRS$
$=0.41+0.59\times(hH)/(hH)CRS$

This equation integrates factors like the height ratio ($HhhH$), the critical height ratio ($HhCRShHCRS$), the pullout force ($PuPu$), cohesion (cc), and dimensions ($BhBh$) to compute the pullout capacity ($PuPu$) of the anchor.

- Simplifying further: $0.367/[((Pu/13)\times 1)/(9)]=0.6270.367/[((Pu/13)\times 1)/(9)]=0.627$
- Resulting in: $0.367=(Pu/13)/9\times 0.6270.367=(Pu/13)/9\times 0.627$
- Thus, $3.303=Pu/13\times 0.6273.303=Pu/13\times 0.627$
- $Pu=109.224$ kN$Pu=109.224$ kN=10.92 tons=10.92 tons

Anchor Load Distribution and Safety Factor Calculation:

- Load factor $Pall=Pu/SFPall=Pu/SF$
- $Pall=10.92/2Pall=10.92/2=5.46$ tons=5460 kg=5.46 tons=5460 kg

Determining the Depth of the Anchored Sheet Pile:

- The total moments are calculated and balanced:
  - $\Sigma MA=0\Sigma MA=0$
  - $\Sigma Mactive–\Sigma Mpassive=0\Sigma Mactive–\Sigma Mpassive=0$
  - $\Sigma MTotal=(0.209D3+1.235D2–0.384D+49.512)–(1.381D3+1.731D2)\Sigma MTotal$ $=(0.209D3+1.235D2–0.384D+49.512)–(1.381D3+1.731D2)$
  - Resulting in $=-1.172D3–0.469D2–0.384D+49.512=-1.172D3–0.469D2–0.384D+49.512$
- The chosen depth DD is approximately 3.324 meters, rounded to 3 meters. According to safety factor guidelines (1.2 - 1.4), $D=1.2$, $D=1.3\times 3 = 3.9meters \approx 4meters$, $D=1.2$, $D=1.3\times 3 = 3.9$ *meters* ≈ 4 *meters*. Consequently, the required length of the sheet pile that penetrates into the ground is 13 meters.

Anchor Diameter Calculation and Installation Specifications:

- With the moment calculated previously and the anchor set at 3.5 meters depth, the active and passive pressures are computed, resulting in a balanced force equation:
  - $\Sigma Pactive=49.272\times 3.5=172.452\Sigma Pactive=49.272\times 3.5=172.452$
  - $\Sigma Ppassive=(55.832+T)\times 3.5=195.412+3.5T\Sigma Ppassive=(55.832+T)\times 3.5=195.412+3.5T$
- Solving for TT gives $32.519t/m232.519t/m2$.
- The anchor diameter ($\phi\phi$) is then calculated based on the tensile strength:
  - $\phi=((113.817\times 1000)/(1/4\pi\times 5460))=5.153$ cm$\approx$5 cm$\phi=((113.817\times 1000)/(1/4\pi\times 5460))$ =5.153 cm$\approx$5 cm
- The anchor block is installed 3.5 meters below the surface, in a stable soil zone that does not experience slippage, with an assumed lateral earth pressure coefficient ($K0=0.4K0=0.4$) and an angle of 40°, leading to a length calculation of $L=10.131m=10mL=10.131m=10m$.

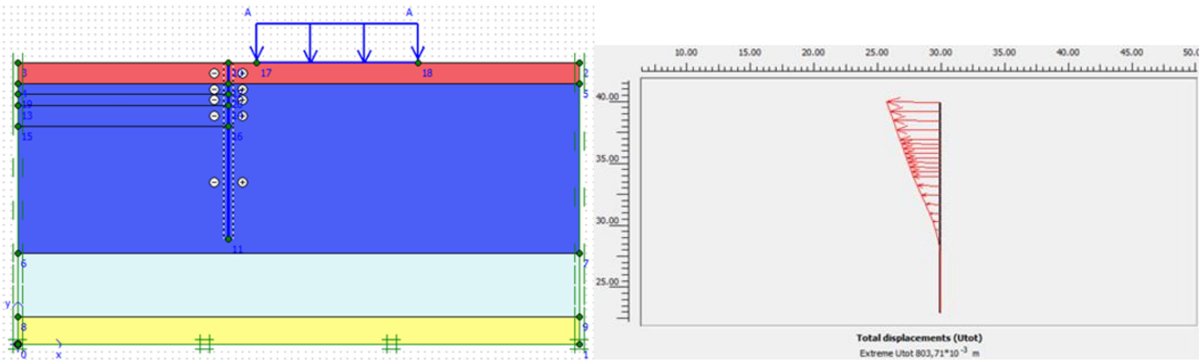

Figure 4. Modeling of Unanchored Sheet Pile

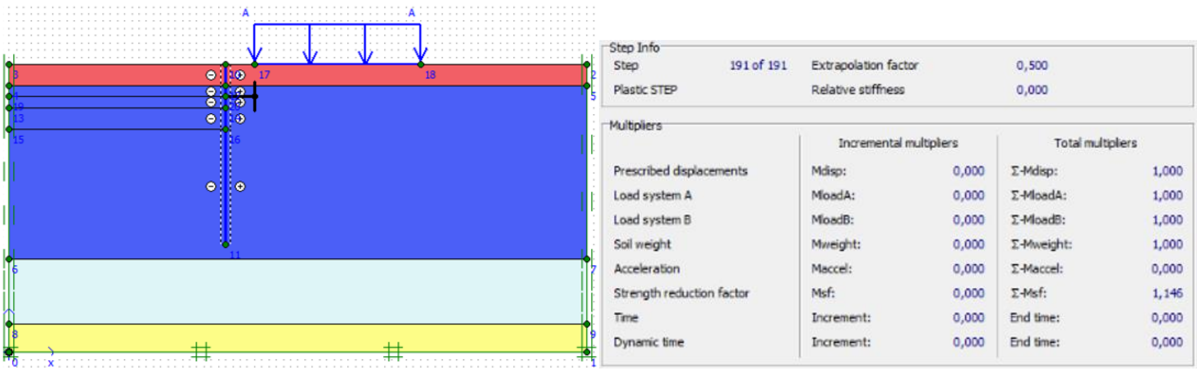

Figure 5. Modeling of Anchored Sheet Pile

This comprehensive anchored sheet pile design ensures structural integrity and stability by meticulously calculating and optimizing each component, from anchor placement to load distribution, tailored specifically to the soil conditions and project requirements.

Modeling Analysis

In the modeling analysis, a comparative study is conducted on the safety factors and lateral deformations between unanchored sheet piles and those with anchors. This analysis helps to understand the structural behavior and the effectiveness of anchoring in sheet pile designs under various conditions.

The table 3 showcases a direct comparison highlighting the shorter length required for sheet piles when anchors are used. Anchored sheet piles, with a length of 13 meters and anchors extending 10 meters, show a higher safety factor of 1.146 compared to the unanchored sheet piles, which have a safety factor of 1 and a length of 19 meters. This difference in safety factors indicates that anchored sheet piles are more effective in resisting lateral movements and soil pressures, resulting in a significant reduction in lateral deformation from 0.00803 meters to just 0.00195 meters.

Referencing Figure 1 and Figure 2, the calculations for active and passive earth pressures (σ'ha and σ'hp) are fundamental in understanding how soil pressures interact with structural elements. The equations provided, $\sigma'_{ha} = \sigma'_v \times K_a - 2c' \sqrt{(K_a)}$ and $\sigma'_{hp} = \sigma'_v \times K_p + 2c' \sqrt{(K_p)}$, are critical for designing effective retaining structures [1]. The influence of earth pressure coefficients (Ka and Kp) on these forces is derived from the Rankine theory, well-established in geotechnical engineering [7]. Figure 3 presents a soil condition and stress distribution diagram at a depth of 9 meters, showing varying coefficients of active earth pressure (Ka1 and Ka2) and a passive earth pressure (Kp) coefficient. These values, calculated from the tangent squared of specific angles, are instrumental in understanding the lateral stress behaviors depending on soil depth and consistency [3].

Table 1 and Table 2 provide the calculated results for active and passive forces and moments, respectively. These tables encapsulate the numeric evaluations needed to assess the feasibility and stability of the sheet pile designs, offering a detailed breakdown of forces and moments anticipated in response to calculated pressures [9], [10].

The analytical models presented in Figure 4 and Figure 5 demonstrate the differences in structural behavior between unanchored and anchored sheet piles. These models are pivotal in visualizing the theoretical data and understanding the practical implications of the calculated active and passive pressures on the sheet piles [6]. Table 3 rounds out the discussion by comparing the length requirements for unanchored versus anchored sheet piles. This comparison is crucial for practical applications, showing how the introduction of anchors can significantly reduce the length of sheet piles needed while enhancing the safety factor and reducing lateral deformation [12], [16]. The impact of anchors on safety and deformation has been extensively studied and supports the findings that anchored systems provide superior stability and performance [8].

Table 3. Comparison of Sheet Pile Length Requirements

No.	Description	Length of Sheet Pile (m)	Length of Anchor (m)	Anchor Diameter (cm)	Safety Factor (SF)	Lateral Deformation (m)
1	Unanchored Sheet Pile	19	-	-	1	0.00803
2	Anchored Sheet Pile	13	10	5	1.146	0.00195

In summary, this discussion brings together theoretical calculations and practical modeling to provide a holistic view of how sheet piles interact with soil pressures. By analyzing both the active and passive pressures alongside actual modeling data, it is possible to optimize the design of sheet piles for specific site conditions, ensuring both stability and efficiency in construction projects. Citations from various studies support the discussed concepts and provide a robust framework for understanding the complex dynamics at play in sheet pile installations [2], [4], [5].

This analysis emphasizes the importance of anchors in enhancing the stability and safety of sheet pile structures, especially in conditions where lateral earth pressures are significant. By comparing these two approaches, it is evident that the use of anchors not only reduces the material requirement by shortening the pile length but also improves the overall performance and safety of the retaining structure.

4. Conclusion

After a comprehensive analysis of the collected data and modeled scenarios, we have identified several key findings regarding the behavior and performance of sheet piles under different conditions:

a. Lateral Earth Pressure at Depth:
   - At a depth of 9 meters within the excavation site, the lateral earth pressure is approximately 19,624 t/m².
   - This substantial pressure highlights the significant lateral forces impacting the retaining structures, necessitating robust design considerations for stability.

b. Depth and Length Requirements for Sheet Piles:
   - Calculations of lateral earth pressure indicate that unanchored sheet piles need a penetration depth of 10 meters, resulting in a total sheet pile length of 19 meters.
   - In contrast, anchored sheet piles require only a 4-meter penetration depth, with a total length of 13 meters.
   - The reduction in required length with the use of anchors underscores their effectiveness in providing additional stability and resistance against lateral pressures.

c. Modeling and Safety Factor Analysis:
   - Modeling results using Plaxis software provide insights into the structural integrity of both anchored and unanchored sheet piles.
   - Unanchored sheet piles achieved a safety factor (SF) of 1, with a lateral deformation of 0.00803 meters.
   - Anchored sheet piles showed an improved safety factor of 1.146 and significantly reduced lateral deformation of 0.00195 meters.
   - This demonstrates that anchored sheet piles experience much less deformation than unanchored ones, highlighting the benefits of anchoring systems in enhancing overall safety and performance.

These conclusions emphasize the critical importance of careful design and implementation of sheet piles, particularly in scenarios with substantial lateral earth pressures. The use of anchors has been shown to significantly improve the stability and reduce the deformation of sheet piles, making it a recommended practice for enhancing the safety and durability of earth-retaining structures in deep excavations. This analysis not only enhances our understanding of the mechanical behaviors involved but also informs best practices for future construction projects requiring similar geotechnical solutions.

References:

[1] B. M. Das, *Mekanika Tanah (Prinsip - Prinsip Rekayasa Geoteknis)*. Jakarta: Erlangga, 1995.

[2] R. Gunanta, "Uji Model Dinding Penahan Tanah dengan Timbunan Gambut Menggunakan Perkuatan Fleksibel Polypropilene," 2014.

[3] M. Toyeb, H. Mubarak, P. Ningrum, and M. Yazid, "Perencanaan Dinding Turap di Tepi Sungai pada Tanah Lunak," *J. Infrastruct. Civ. Eng.*, vol. 2, no. 2, pp. 121–126, Jul. 2022, doi: 10.35583/jice.v2i2.23.

[4] Martini, Shyama Maricar, and Hendra Setiawan, "Perencanaan Konstruksi Turap sebagai Pengganti Dinding Penahan (Studi Kasus Jalan Lingkar Donggala)," *Infrastruktur J. Tek. Sipil Univ. Tadulako*, vol. 2, no. 2, pp. 96–104, 2012.

[5] F. Chalid, "Program Studi Teknik Sipil Fakultas Teknik Universitas Medan Area Medan 2018," 2018.

[6] N. L. Sa'adah, K. Prihatin, and P. Suroso, "Perancangan Turap Berjangkar pada Tepian Sungai Mahakam di Jalan Kh. Mas Mansyur Loa Bakung Samarinda," 2017.

[7] H. C. Hardiyatmo, *Mekanika Tanah 1 Edisi Keenam*, 2012.

[8] I. Sepriyanna and W. F. Damanik, "Analisis Perbaikan Pergeseran Dinding Contiguous Bored Pile dengan Permodelan Plaxis V 8.2 Studi Kasus: Proyek Pembangunan Basement Ciputra International Phase 1 Jakarta Barat," 2016.

[9] Universitas Katolik Parahyangan and D. Yulianto, "Analisis Stabilitas Turap Berjangkar pada Tepi Sungai Tenggarong Kabupaten Kutai Kartanegara, Kalimantan Timur," in *Pengembangan Infrastruktur Berkelanjutan untuk Meningkatkan Daya Saing Bangsa*, ITP Press, Jul. 2017, pp. 204–208, doi: 10.21063/SPI3.1017.204-208.

[10] M. A. Rifaldi and E. Priadi, "Studi Perilaku Deformasi Lateral Turap di Angkur (Anchored Sheet Pile) di Lereng Sungai Kapuas."

[11] Nazarova, E. V., Kaloshina, S. V., & Zolotozubov, D. G. (2021, June). The choice of a metal sheet piling for the construction of the foundation pit. In Journal of Physics: Conference Series (Vol. 1928, No. 1, p. 012049). IOP Publishing.

[12] Dinakar, K. N., & Prasad, S. K. (2014). Behaviour of tie back sheet pile wall for deep excavation using plaxis. International Journal of Research in Engineering and Technology, 3(6), 97-103.

[13] Das, M. R., & Das, S. K. (2015). Optimal Design of Sheet Pile Wall Embedded in Clay. Journal of The Institution of Engineers (India): Series A, 96(3), 249–258. doi:10.1007/s40030-015-0128-9

[14] Eskandari, L., & Kalantari, B. (2011). Basic Types of Sheet Pile Walls and Their Application in the Construction Industry--a Review. Electronic Journal of Geotechnical Engineering, 16(1).

[15] Nishanthan, R., Liyanapathirana, D. S., & Leo, C. J. (2012). Analysis of pile behavior adjacent to a deep excavation.

[16] Hidayat, I., & Kusuma, A. (2021). Permodelan Perkuatan Sheet Pile Menggunakan Analisis Kesetimbangan Batas dan Elemen Hingga. Jurnal Online Sekolah Tinggi Teknologi Mandala, 16(1), 87-96.