

Research Article

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Static behavior of piled raft foundation in clay

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Abstract: Wall piles supported with anchors are considered one of the most prevalent types of engineering support. This research includes studying the behavior of wall piles through a numerical parametric study using the FE-method program (PLAXIS 2D). The study includes the most influencing factors such as the angle of the inclination, the vertical spacing between the rows of anchors, and the distance of the first row of anchors from the ground surface. The effects of these factors on the stability of the wall were studied. Optimal positioning of the anchors is crucial, as it maximizes their effectiveness and contributes significantly to reducing the overall construction costs. The use of a guys queue for the economic aspect saves the cost of executing two guys queue because the effect of having two rows does not significantly change the transfer values. The optimum angle of inclination of the tensioner row is 15° in favor of safety, and as it gives good stability of the wall to the wedge wall, with an increase in this angle, the horizontal movement decreases. The first optimum dimension for a row of guys from the horizontal surface of the earth is $O = 25\%H$. Decrease the values of horizontal movement of the wall by increasing the angle of friction.

Keywords: wall pile, ground anchors, basin foundation, parameters of the specifications of the anchor, excavation support, finite element method

1 Introduction

As urban development expands due to population growth, there is a heightened demand for high-rise buildings [1]. This has led to various considerations and approaches to accommodate the increasing population in urban areas.

Each of these methods has advantages and disadvantages, and it is important to know the limits and areas of difference for each method [2]. The use of numerical modeling as the finite element method and finite differences provided a means to predict the behavior of facilities and maintain their stability. To reduce settlements to an acceptable amount, the foundation shall be made of a number of necessary piles, and the loads shall be transferred from the structure, via raft, partly to the foundation soil and partly to the piles (the load combined between the raft and the piles) [3,4]. The contact area of the foundation with the soil is much more than any other type of foundation as in the case of the raft foundation, so the load is distributed over a larger area and soil shear is possible. This leads to lowered and less pressure on the soil, which is beneficial for the foundation [5,6]. In stacked raft foundations, the combined load between piles and raft is affected by the complex interaction between soil and structure. Stacked rafts are made more efficient and economical by optimizing the number and location of outriggers [7,8].

1.1 Research importance and objectives

- The aim of the research on the mud foundation basins is to analyze the behavior of the wedge walls supported by the guys as static behavior using the finite element method through a mathematical model.
- Achieving sufficient accuracy and the best parametrically studied cement solution.
- The study highlights the most important design considerations, especially for this type of wedge wall.
- To determine the optimal economic situation for the ranks of the comrades, display the plans of soil transfers behind the wall.
- The research presents a realistic example of using the static study and the reinforcement method, as the reinforcement requires a large implementation time and a large cost, which makes predicting the behavior, stability, and design of the walls a matter that requires a lot of effort. Accuracy and error can lead to disastrous results. Guys are designed with a results statement while selecting the best solutions with the least cost and time.

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1.2 Research methodology

The research depends on the comparative analytical method and includes the following stages.

1.2.1 Finite element modeling

Creating a numerical model involves revisiting a previously examined free wedge wall. This process includes defining the realistic soil characteristics, determining external loads, specifying the depth of the foundation pit, and implementing an applied clay soil in the analysis.

In the modeling, the PLAXIS 2D program was used for numerical modeling by the method of Al-Aasr Al-Fatihah.

The mathematical model was calibrated using Moore–Coulomb's law, and an appropriate mathematical model was developed with all its properties and terminal conditions.

1.2.2 Parametric study

The effect of several parameters included in the design of the wedge wall supported by tensions on the stability and balance of the wall was studied.

1.2.2.1 Numerical model

We utilized numerical programs primarily based on the finite element method. However, these programs present certain challenges, including the selection of a suitable soil model, determination of soil parameters dependent on initial soil conditions, consideration of surrounding conditions and analysis type, as well as interpretation and evaluation of the results.

1.2.3 The reference studies and the field model

A model of a wedge wall reinforced with three-row anchors was adopted for one of the previous studies (Anton Szavits Nossan, [8]) with clay soil, as shown in Figure 1.

1.2.3.1 Used symbol

The symbols and some hypotheses of previous studies were adopted according to Figure 2, where O denotes the first row of guys from the horizontal surface of the earth and ranges between 12.5 and 25% according to the hypothesis of Jitesh Chavda; n is the horizontal dimension between the face of

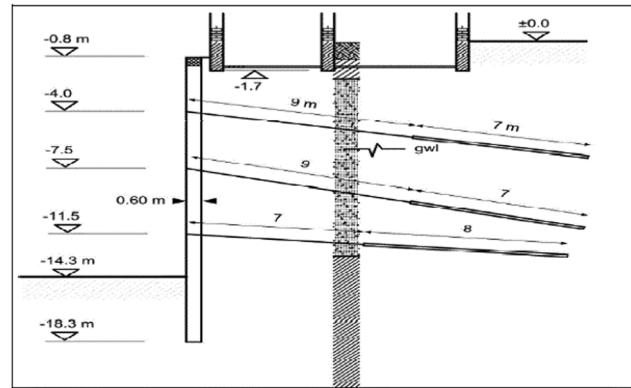


Figure 1: Data on the wall, tensions, and elevations.

the wedge from the side of the foundation basin and the point of intersection of the slip line with the ground surface, assuming the researcher Jitesh that the slip line is inclined from the horizon at an angle of $45 + \phi/2$, starting from the bottom of the inner wedge foot; L_{tot} is the total length of row i of turnbuckles; $L_{geo} = L_{bound}$ is the length of the injected body represented in the program as a geogrid; $L_{ai} = L_{unbound}$ is the free length of row i of turnbuckles; and M is the perpendicular distance between the slip line and a straight line parallel to it, taken as a percentage, ≥ 1.5 .

H , $r_1 = 6D$ or 1 m is the vertical distance between the earth's horizontal surface and the center of the first injected body; N_A is the number of rows of guys; M_c is the flexible model that is fully plastic; H_{max} is the maximum horizontal movement in the wall; H_{mmax} is the maximum horizontal transfer of the measured field values; DH is the value of the difference between the maximum transfers; $SA = 2.5\text{ m}$ is the horizontal spacing between turnbuckles in each row; H_{all} is the allowable horizontal transition in a post-reinforced wedge and is equivalent to $H/300 = 0.048\text{ m}$ according to the German Standard.

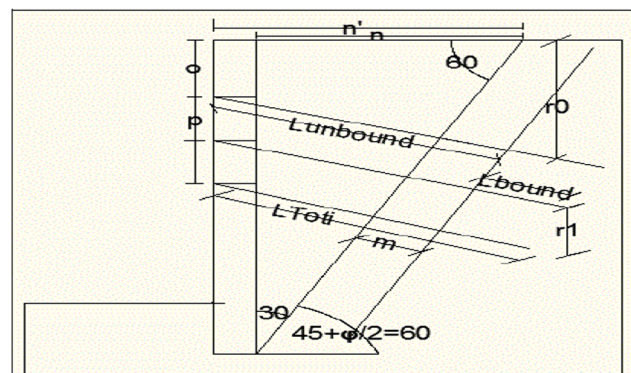


Figure 2: Some of the symbols used in the search.

Table 1: Specifications of the materials entered

Symbol	Denotation	Value	The single
Eref	Modulus of elasticity of the sphenoid wall	25	GPa
V(ru)	Poisson coefficient for concrete walls	0.3	—
Gref	Shear modulus of the sphenoid wall	9.615	GPa
Eoed	Modulus of elasticity	33.65	GPa
Yb	Volumetric weight of reinforced concrete	25	kPa
EA1	The hardness of each tensioner in the first row	117,000	kN
EA (2,3)	The stiffness of each tensioner in the second and third rows	146,000	kN
EA	The stiffness of the geogrid representing the injected body	30,000	kN

GPa, giga pascals; kN, kilo newtons; kPa, kilo pascals; kg/m^3 , single density-specific gravity.

1.2.3.2 Material specification

The wall of the foundation pit is made of cast-in-place concrete with a thickness of 0.6 m with contact stakes, using linear elastic behavior in modeling, and the wall is supported by three rows of anchors with different angles of inclination.

Specifications of the materials entered in the program wedge wall, each row of anchors, and the injected body are shown in Table 1.

1.2.3.3 Dimensions and terminal conditions

The dimensions were determined according to the fields allowed by Briaud and Lim in 1997 [2], and the dimensions are shown in Figure 3, where $L = 3-4B$ is the width of the model; B denotes the model height; and W is the width of the additional load distributed over a linear meter. We show the fossil. Be is the distance from the edge of the model to the outer edge of the reinforced wall; T is the

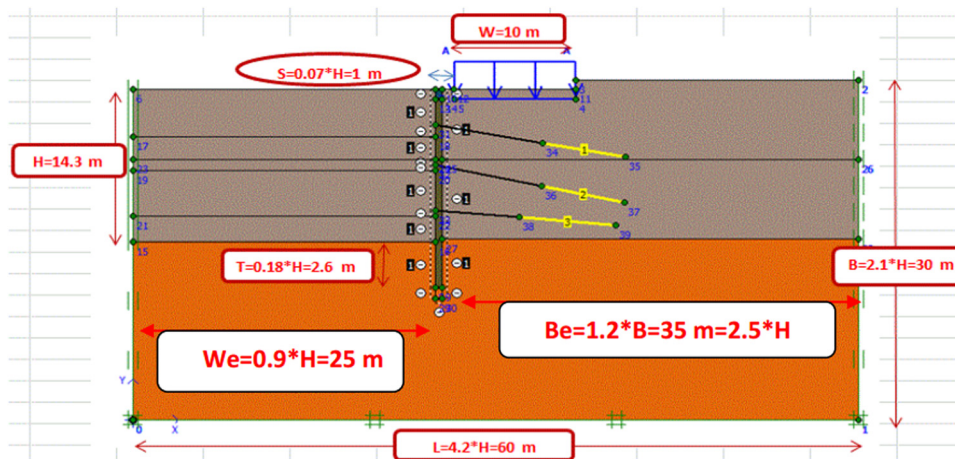
suture depth; and S denotes the left inner end of the additional load from the face of the right wall opposite it.

The additional load of the old building adjacent to the excavation was modeled as a uniformly distributed load of 72 kN/m^2 .

2 Discussion and the studied sports model

– As for the terminal conditions and dimensions of the studied model, they are according to Figure 3.

- Concerning the specifications of the drop wedge wall, the foundation basin is supported by a wedge wall consisting of adjacent pegs, and the spacing between the centers of the pegs is $Sh = D$, and according to the researcher in reference [2], $D = Dp = 60 \text{ cm}$, which is the diameter of the stake. The specifications of the studied wedge wall are as follows: the volumetric

**Figure 3:** Boundaries and dimensions of the field model.

weight of reinforced concrete is 25 kPa; the modulus of elasticity of the Eref is 25 GPa; and the Poisson's modulus is 0.3.

- With regard to the specifications of the tensioners studied, they are identical to the injected body in all rows. The specifications are as follows: the hardness of the first row of EA turnbuckles is 117,000 kN; the hardness of the second- and third-row turnbuckles is 146,000 kN; and the injected body stiffness for all grades is 30,000 kN.
- As for the proposed soil specifications, clay soil was used, which extends to the end of the foundation depth, followed by hard clay, depending on the findings of Mollahasani [3]. The following are numerically studied soil properties:

Material type: drained hard clay and drained pelleted clay.

The unsaturated density (above the water level) is 18 kg/m^3 for fine clay and 21 kg/m^3 for hard clay.

The saturated density is 19 kg/m^3 for fine clay and 21 kg/m^3 for hard clay.

The transmittance in the horizontal direction is 0.0001 m/day.

The transmittance in the vertical direction is 0.0001 m/day.

The soil modulus of elasticity is 9,000 kPa for sifted clay and 300,000 kPa for hard clay.

The effective cohesion is 20 kPa for sintered clay and 25 kPa for hard clay.

The effective friction angle is 29 grit and 30 grit.

The volumetric expansion angle is 0 in both cases.

Poisson's factor is 0.25 for vegetated clay.

- User Code of Conduct:

The researcher found [3] that the best law of matter used in alluvial soils, which accurately represents soil deformations and mimics reality, is Mohr–Coulomb's law adopted in modeling.

- Parametric study:

The wedge wall was modeled as a free wall in the soil without reinforcement with tensioners. The modeling resulted in the deformation of the wedge wall and its rotation toward the foundation basin with a value of $H_{\max} = 6.27 \text{ cm} > H_{\text{all}}$ at the top of the wall according to Figures 4 and 5. Therefore, the wedge wall needs to be reinforced with an appropriate number of tensioners determined during the parametric study.

The values of some constants have been adopted, which we will refer to when studying.

$$(m = 0.15 H, O = 0.25 H, p = 0.25 H, D = 60 \text{ cm}, \\ L_{\text{geo}} = 7 \text{ m } \alpha = 15^\circ)$$

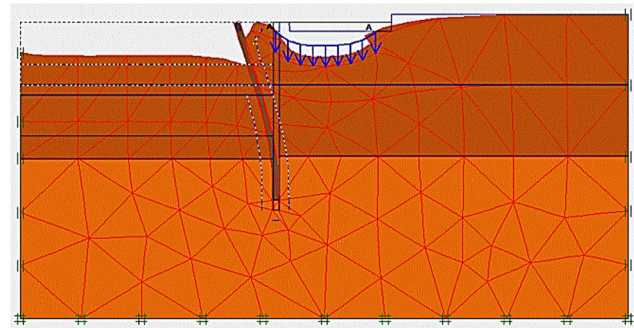


Figure 4: Free wall deformation without reinforcement by tensioners.

2.1 Effect of the number of rows of guys nA

An angle of inclination from the horizontal of 15° was used, and the reinforcement was carried out with goggles and two rows of goggles $nA = 1$ and 2.

Figure 6 shows the convergence of the shape of the two curves in the two cases, as well as the significant decrease in the horizontal transmission, which causes the wall to withdraw toward the soil so that it resists the lateral push of the soil and changes the direction of movement of the wall.

The $H_{\max} = 4.35 \text{ cm} > H_{\text{aaa}}$ in the case of a row of guys, and the $H_{\max} = 4.3 \text{ cm} > H_{\text{aaa}}$ in the case of two guys, and the

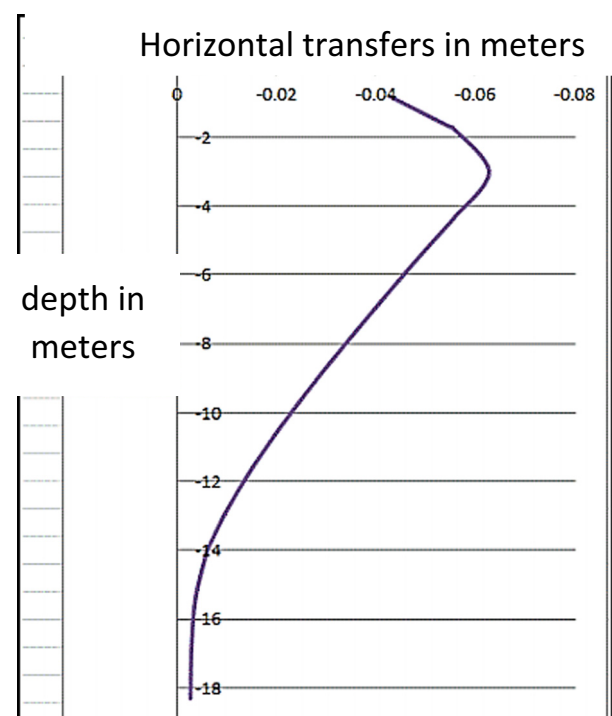


Figure 5: Horizontal transition with the depth of the free wall without tensioners.

DH = 0.05 cm and is equivalent to 1.15%, which is a small difference, so one row of guys will be approved.

The height of the transition is at the top of the wall, and the shape of the curve is wavy. Therefore, it is sufficient to use one row of guys from an economic point of view to save the cost of implementing two guy rows, since the effect of the presence of two rows does not significantly change the transfer values. There is no importance in studying the presence of a second row of tension bands, because its effectiveness is low since the presence of a female group of tension bands achieves sufficient and great stability for the wedge wall.

The effect of changing the angle of inclination of the rows of Alpha Guys:

The case of $nA = 1$ was adopted to choose the angle that achieves the best stability for the wall. Several values of the inclination angle were studied: 5°, 10°, 12°, 15°, and 20°, and the rest of the parameters were fixed as shown in Figure 7.

Figure 7 shows a slight decrease in transmission with an increase in the angle of inclination in the cohesive clay soil due to the decrease in the effectiveness of tension on friction according to the study by Wen (2012) (<https://doi.org/10.1155/2020/2109535>). The curve that gives the lowest values of horizontal transmission is the angle case curve of 15° and 20°.

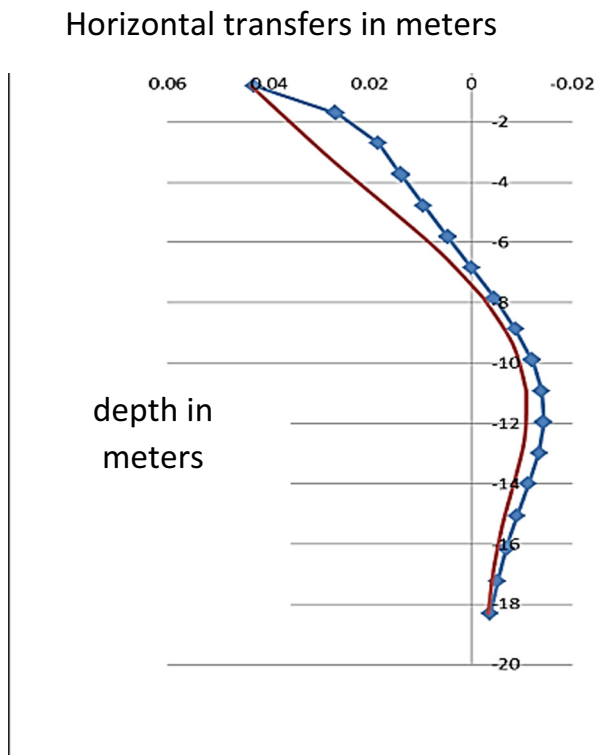


Figure 6: Comparison of the curves of the horizontal transition values with depth.

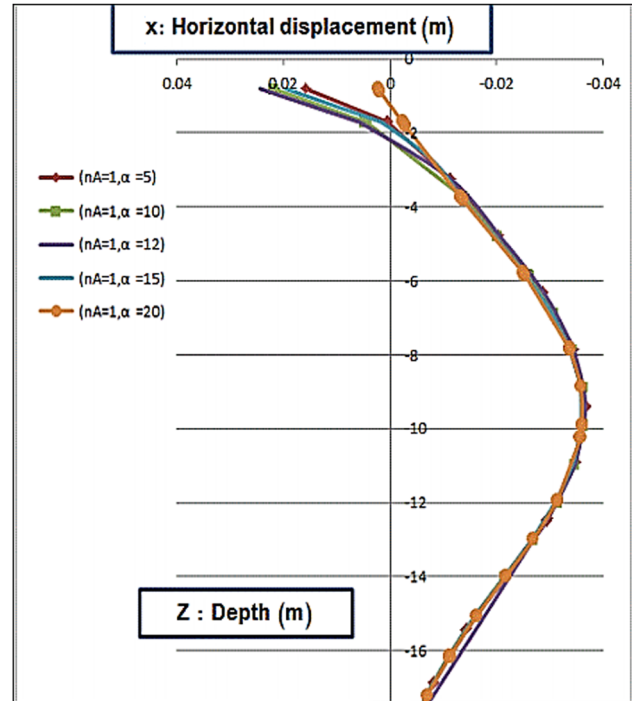


Figure 7: Comparison of the horizontal transition curves with depth for the case of two shadings at several values of inclination angle.

Figure 8 shows the value of $H_{\max} = 3.582$ cm in the case of an angle of 15°. In the case of $H_{\max} = 3.6$ cm and the angle is 20°, the DH = 0.015 cm between the two cases for the angle value of 15° and 20°, which is a small difference and is equivalent to 0.5%.

The angle of 15° was adopted as the ideal angle, and researcher Sliwinski (<https://doi.org/10.1007/978-1-349-13258-4>) in 1971 considered that the ideal angle of inclination of the tension in the clay should be <20°. Esame ([https://doi.org/10.1016/0032-5910\(75\)80036-2](https://doi.org/10.1016/0032-5910(75)80036-2)) in 1974 found that the best tension angle makes the tensioner work with the greatest tensile strength <15° in clayey granulated soils at an average soil friction of 25.

2.1.1 Effect after the first row of tensioners on the horizontal surface of the earth (O)

The angle adopted was 15°, and several values were given to (O) as a percentage of the height of the foundation basin as follows (Figure 8):

$$O = 0.1H, 0.125H, 0.15H, 0.2H, 0.25H, 0.36H, 0.35H$$

Figure 8 shows the decrease in the values of the horizontal wall transition as it increases (O); the curve representing the case of $O = 25\%H$ represents a wavy curve with a low transmission value and its peak in the middle of the wall. In the case of $O = 35\%H$, $H_{\max} = 3.25$ and $H_{\max} =$

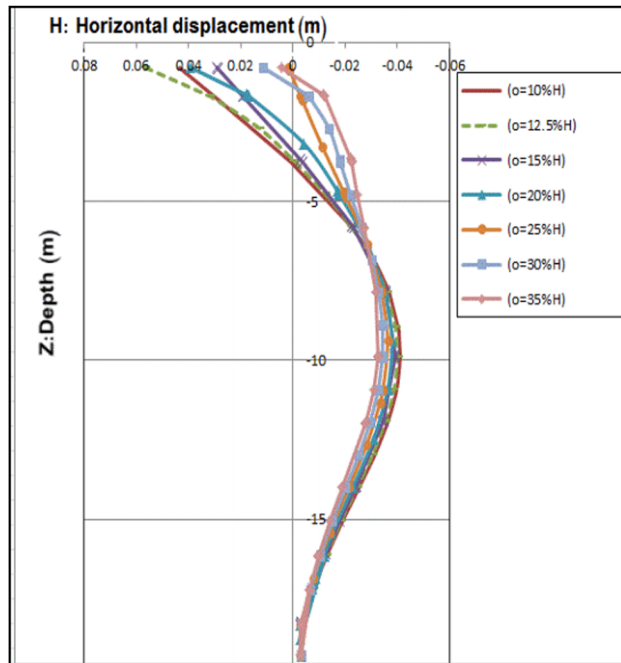


Figure 8: Comparison of the horizontal transition curves over the entire length of the wall with the depth at several values of (ϕ).

3.62 cm. In the case of $\phi = 0.25H$, all values are low and within the permissible limits.

Furthermore, $DH = 0.1\text{ cm}$ equals 10.2%, which is a small difference. From the above, the $\phi = 0.25H$ case was adopted as an ideal case for ease of implementation, which is consistent with Naveen's 2014 study.

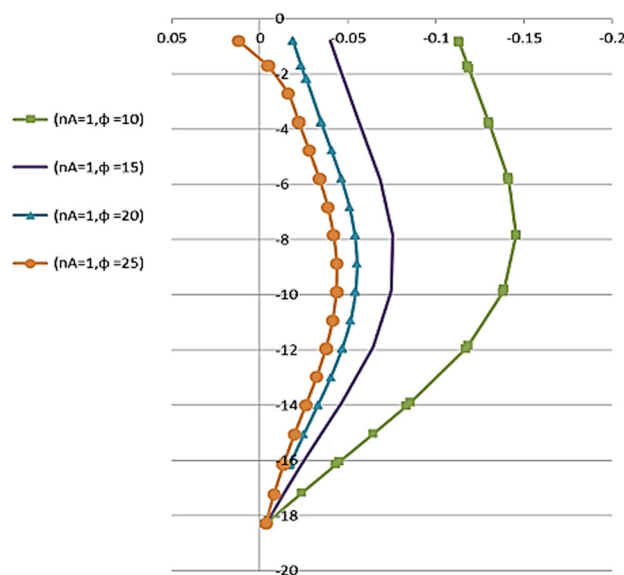


Figure 9: Curves of horizontal transition over the entire length of the wall with depth at different values of the soil friction angle held behind the wedging wall.

2.1.2 Effect of changing the soil friction angle parameter behind the wedge wall

It was adopted after the first row of tensioners from the ground surface $\phi = 0.25H$; the friction angle of 5° was not used due to the collapse of the wall at this value; and several values were given for the angle of friction of the soil reserved behind the peg wall: 10° , 15° , 20° , and 25° , as shown in Figures 8 and 9.

3 Conclusions

1. The use of a guys queue for the economic aspect saves the cost of executing two guys queue because the effect of having two rows does not significantly change the transfer values.
2. The optimum angle of inclination of the tensioner row is 15° in favor of safety, and as it gives good stability of the wall to the wedge wall, with an increase in this angle, the horizontal movement decreases.
3. The first optimum dimension for a row of guys from the horizontal surface of the earth is $\phi = 25\%H$.
4. Decrease the values of horizontal movement of the wall by increasing the angle of friction.

3.1 Recommendations

- Due to the complexity of the studied issue and its containment of very many parameters, it is recommended to conduct a parametric study for this type of wall and reinforcement using multiple numerical programs to compare the results and support the results.
- It is recommended to conduct a parametric study for more parameters such as lowering the groundwater level, the depth of the wall penetration, the type and specifications of the impounded soil, and the expansion of the studied parameters.
- It is recommended to study the stability of the wedge walls, taking into account the dynamic analysis of the wall.

Conflict of interest: Authors state no conflict of interest.

Data availability statement: Most datasets generated and analyzed in this study are comprised in this submitted manuscript. The other datasets are available on reasonable request from the corresponding author with the attached information.

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