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UNCOUPLED ANALYSIS OF PILES STABILIZED TRANSMISSION TOWER SLOPES

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ABSTRACT

It is a common engineering practice to adopt piles to improve the stability of potentially unstable slopes. In this paper, parametric analysis of a homogeneous transmission tower slope stabilized with a row of small diameter steel piles is conducted using an uncoupled numerical method in which the pile response and slope stability are considered separately. The transmission tower slope stability is analyzed using the limit equilibrium solutions, and the stabilizing pile-soil system is modeled as a simple beam on subgrade reaction foundation. Attempts have been made to study the effect of soil property, slope geometry, pile property, pile spacing and pile position on the safety factor of the transmission tower slope stabilized with small diameter steel piles. The study shows that they have a combined effect on the performance of small diameter steel piles to stabilize transmission tower slopes.

Keyword: stability analysis, transmission tower slope, stabilizing piles, uncoupled analysis, safety factor.

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INTRODUCTION

The stabilization of slopes by installing piles has been used as an effective solution against unstable slopes in recent years [1-15]. In the last decades, various solution methods have been proposed by researchers to study and analyze the soil-pile interaction in the anti-slide pile to stabilize unstable slopes. They may be categorized into analytical methods [1-8] and numerical methods [9-15]. The analytical methods such as the pressure and displacement-based methods are uncoupled solutions in which the slope stability and pile response are considered separately. Limit equilibrium-based approaches have been widely used for slope stability analysis in analytical methods due to their simplicity and easy application. The numerical methods such as the finite element and finite difference methods can provide the ability to model complex pile-slope problems such as pile-soil interactions using advanced soil models but they can be time-consuming and computationally expensive.

Transmission tower slope failures are a relatively frequent problem. The stabilization of unstable transmission tower slopes has been an important geotechnical problem that requires to be addressed to ensure the functioning of the transmission towers. Small-diameter steel stabilizing piles can provide feasible practical solutions to transmission tower slopes with limited space and access. There are several advantages of using small diameter steel piles compared to larger concrete piles and drilled shafts as a slope stabilization method in transmission tower slopes. The small diameter steel piles can be installed rapidly to improve the slope stability avoiding transmission tower failure and disrupting power supply. However, there is little research about the use of small diameter steel piles for stabilization of an unstable transmission tower slope.

The aim of this paper is to evaluate the performance of small-diameter steel piles to stabilize transmission tower slopes. In this study, a parametric investigation was carried out to examine the effect of a row of small-diameter steel piles on the stability of the transmission tower slope using an uncoupled analysis, in which the pile response and slope stability are considered separately. Numerical results are presented and the important parameters affecting the performance of a row of small steel piles used for transmission tower slope stabilization are investigated and discussed.

METHOD OF ANALYSIS

The stability of the transmission tower slope stabilized with a row of passive piles is analyzed by using a simplified approach based on an uncoupled formulation in which the pile response and slope stability are considered separately. Figure-1 shows a row of small diameter steel pile subjected to lateral soil pressure at the critical sliding surface, where the soil mass is divided into an unstable upper layer (the passive part of pile) and a stable lower layer (the active part of pile). The global stability of the transmission tower slope is analyzed initially using GEO5 Slope Stability commercial program [16] based on limit equilibrium approach to determine the critical slip surface position, the active and passive forces that have to act on the stabilizing piles to meet the required safety factor. These results are then utilized in the GEO5 Anti-Slide Pile commercial program [17] in which the stabilizing pile-soil system is modeled as a simple beam on subgrade reaction foundation, to calculate the internal forces, bending moment and displacement of the stabilizing piles.

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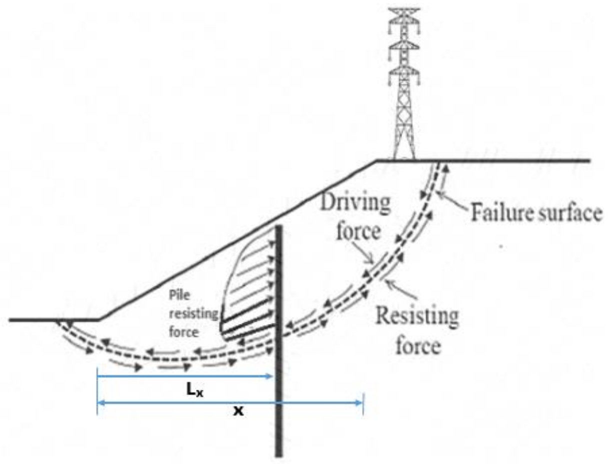

Figure-1. Stability analysis of transmission tower slope stabilizing with piles.

VALIDATION OF THE PRESENT METHOD

The validation of the present method has been performed by comparing with results from other methods. Cai *et al*. [9] and Jeong *et al*. [10] performed coupled and uncoupled finite element analyses repectively, to study effect of using a row of piles for stabilizing slopes. The idealized homogeneous soil slope properties are: height= 10m, gradient= 1V:1.5H, unit weight= 20.0 kN/m^3, cohesion= 10.0 kPa and friction angle= 20.0˚. A row of steel tube piles of 0.8m in diameter (d) was used.

Figure-2 shows that the slope safety factor with stabilizing piles decreases with increasing pile spacing (s) as computed by the three different methods. The results computed by present method are similar to those computed by the coupled and uncoupled finite element methods.

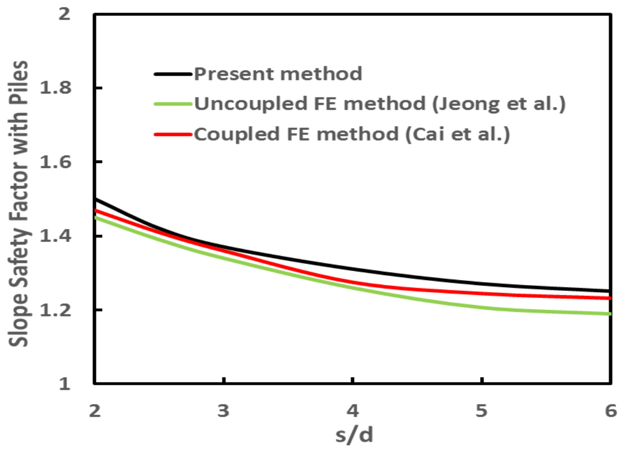

Figure-2. Effect of pile spacing (s) on factor of safety (L_x/x=0.5).

Figure-3 shows the effect of the pile position (L_x) on the safety factor of a slope with stabilizing piles. The numerical results obtained by the present method and coupled finite element method indicate that the optimum pile position for largest safety is near middle of the slope. However, the results computed by the uncoupled finite element method show that the optimum pile position for largest safety is located slightly towards the crest of the slope. The soil pressure acting on the piles placed near the middle of the slope is usually larger than that on the piles placed close to the crest [9, 10].

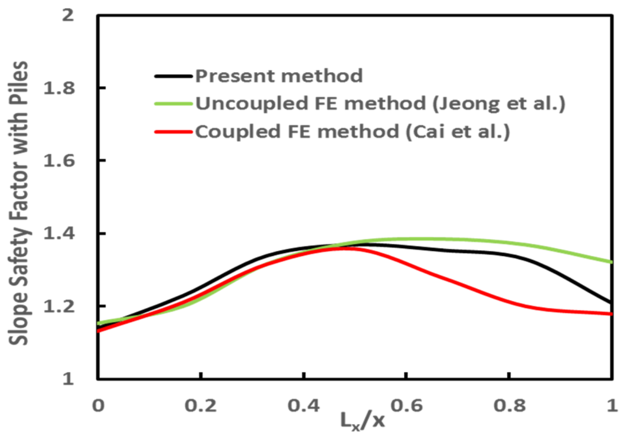

Figure-3. Effect of pile position (L_x) on factor of safety (s/d=3).

PARAMETRIC STUDY

The perforamnce of using small diameter steel piles for stabilizing transmission tower slopes was investigated using the present uncoupled analysis on some important parameters such as the soil properties, slope geometry, pile properties, pile spacing and pile position in the transmission tower slope. A row of small steel piles installed in a transmission tower slope shown in Figure-1 was investigated. In order to study the effect of these parameters on transmission tower slopes stabilized by a row of small steel piles, some reference parameters are used in the study. The properties of the steel pile are: diameter (d)= 90 mm, thickness= 5 mm and length (L)= 6 m. The homogeneous weathered residual soil slope properties are: cohesion (c)= 5 kPa, friction angle (ϕ)= 35˚, unit weight= 19 kN/m^3 and slope height= 20 m. The water table was not considered here. A transmission tower with 996 kN vertical load was assumed to be located on the slope crest. These soil and pile proprties were used in parametric study unless otherwise stated.

There are several major parameters that could affect the pile-slope system to increase the safety factor of the stabilized transmission tower slope. Some of them are the soil properties, slope geometry, pile properties, pile spacing and position in the transmission tower slope.

Figure-4a shows the transmission tower slope safety factor with stabilizing piles (F_p) decreases with increasing pile spacing (s). The smaller the pile spacing (s), the larger is the passive resisting force developed per unit width resulting higher safety factor of the transmission tower slope. Figure-4b shows the maximum pile displacement increases with increasing pile spacing (s). When the pile spacing (s) is increased further, the soil deformation area is larger for the soil flow mode to form around the pile.

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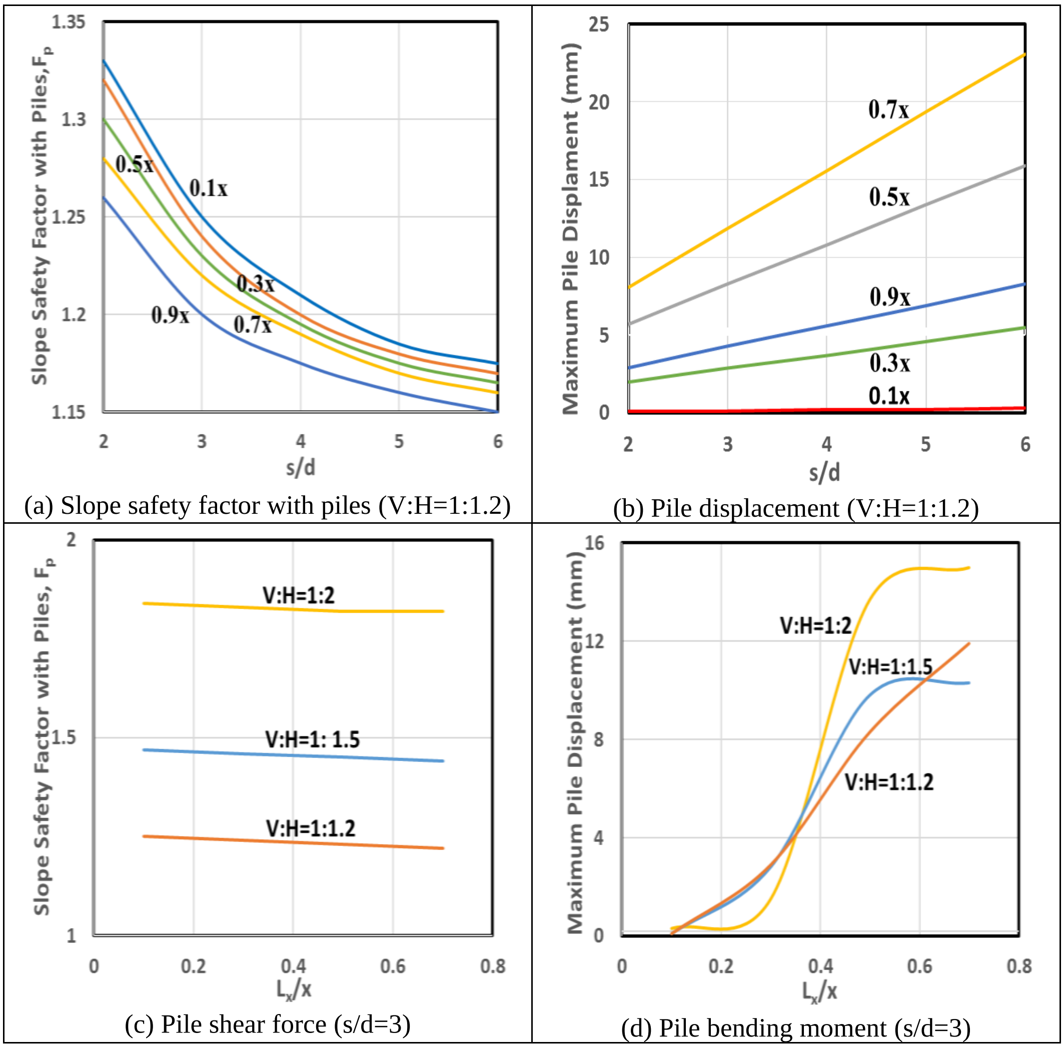
It was found that the slope safety factor (F_p) decreases with respect to increasing slope inclination as shown in Figure-4c. This is because as the slope inclination increases, the slope driving force increases and the soil downslope of the pile began to provide significant less resistance to pile movement due to a higher tendency for slippage. Figure-4d shows the corresponding maximum pile displacement decreases with increasing slope inclination.



(a) Slope safety factor with piles (V:H=1:1.2)
(b) Pile displacement (V:H=1:1.2)
(c) Pile shear force (s/d=3)
(d) Pile bending moment (s/d=3)

Figure-4. Effect of pile spacing and slope inclination on pile-slope system.

The slope safety factor (F_p) increases with increasing soil strength parameters (cohesion and friction angle) as illustrated in Figures 5 and 6. The increasing soil strength parameters changes the main mode of the pile movement from translation to rotation. The corresponding maximum pile displacement, shear force and bending moment decrease with increasing soil strength parameters.

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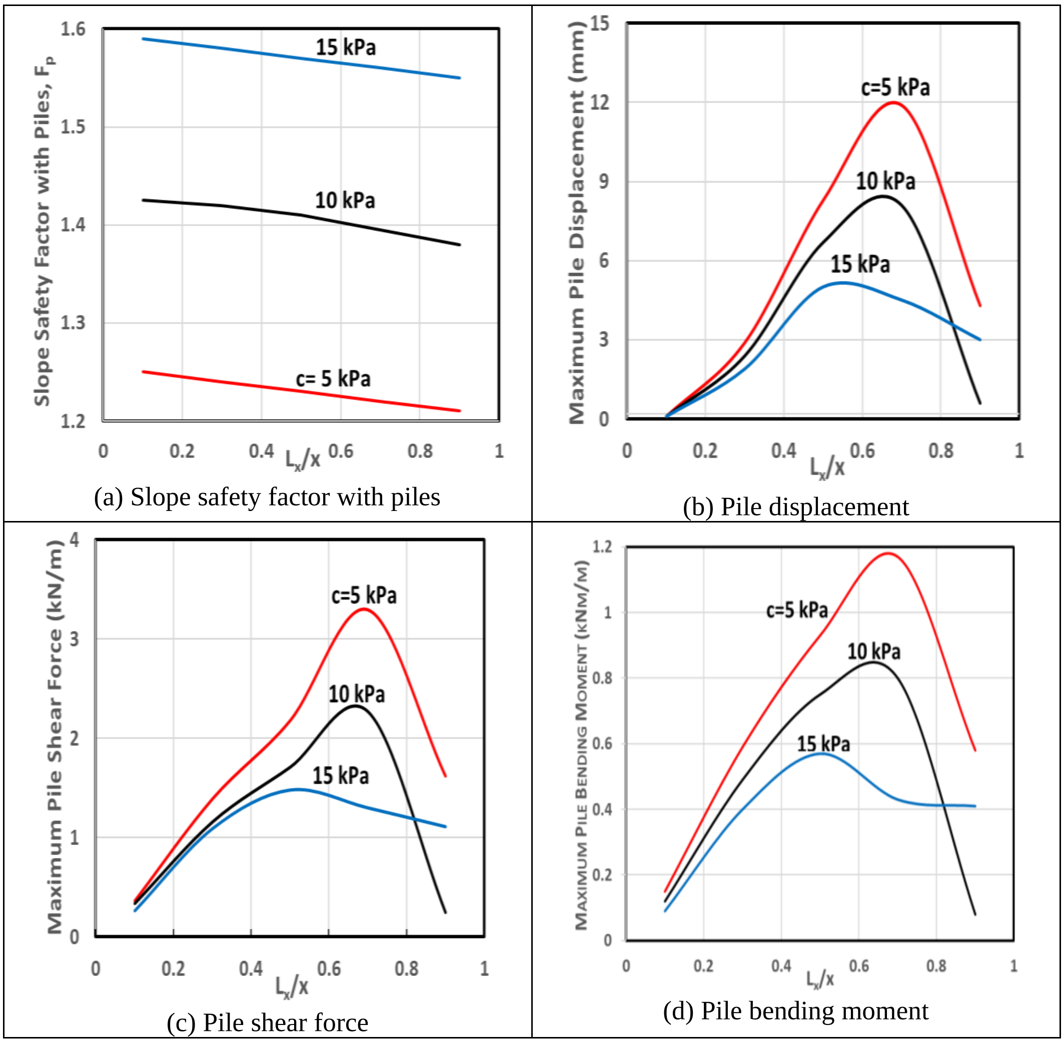

(a) Slope safety factor with piles

(b) Pile displacement

(c) Pile shear force

(d) Pile bending moment

Figure-5. Effect of soil cohesion on pile-slope system (s/d=3 and 1V:1.2H).

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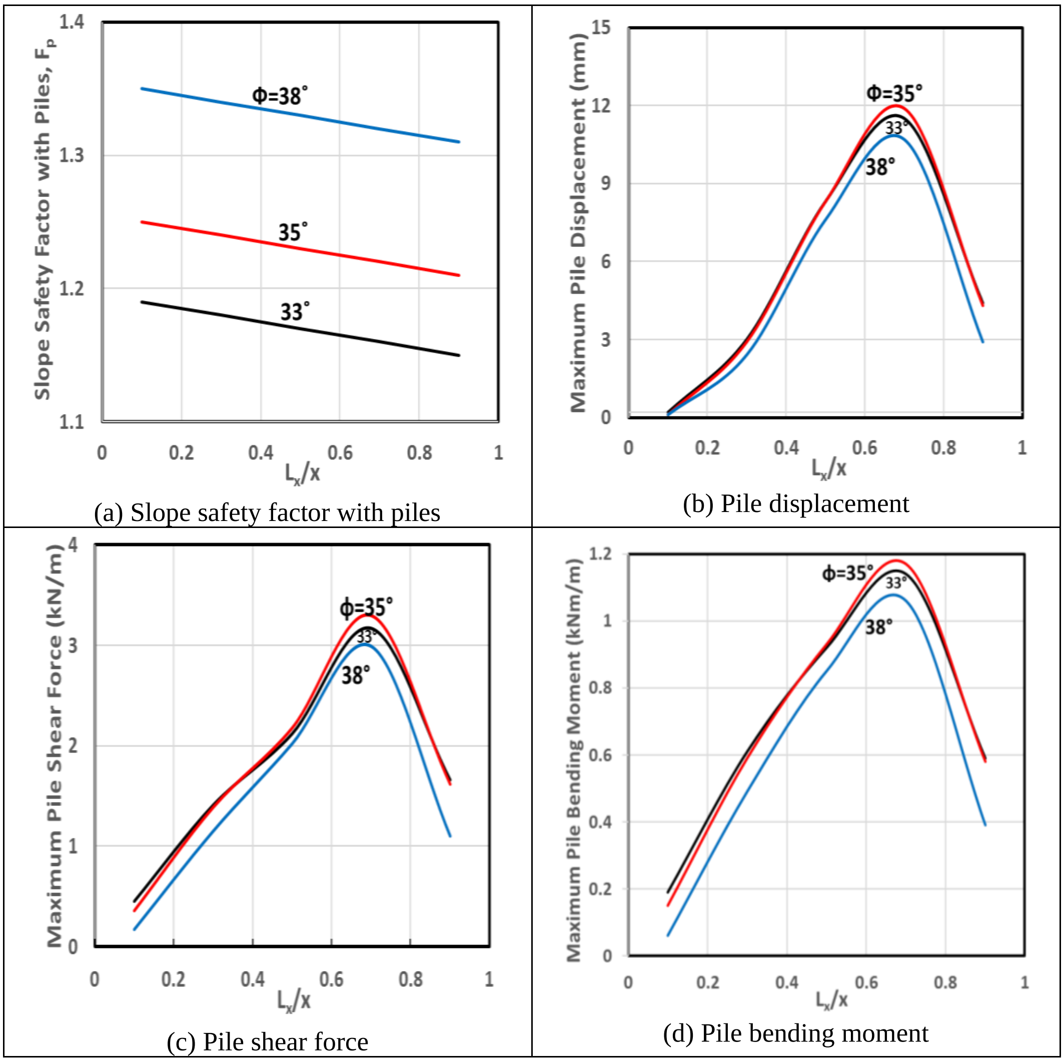

Figure-6. Effect of soil friction angle on pile-slope system (s/d=3 and 1V:1.2H).

The slope safety factor (F_p) increases with increasing pile diameter (d) with constant pile length (L) as shown in Figure-7. The corresponding maximum pile displacement decreases with increasing pile diameter. This was due to the pile stiffness increases with increase in moment of inertia that depends on the diameter of the pile. Increase in diameter of pile reduces maximum displacement of the pile due to increase in structural stiffness. The larger diameter pile gives minimum displacement but a greater bending moment value. Whereas smaller diameter pile gives maximum displacement but lower bending moment value. The stiffer piles could provide greater resistance to slope movement and are more effective in mitigating an unstable transmission tower slope.

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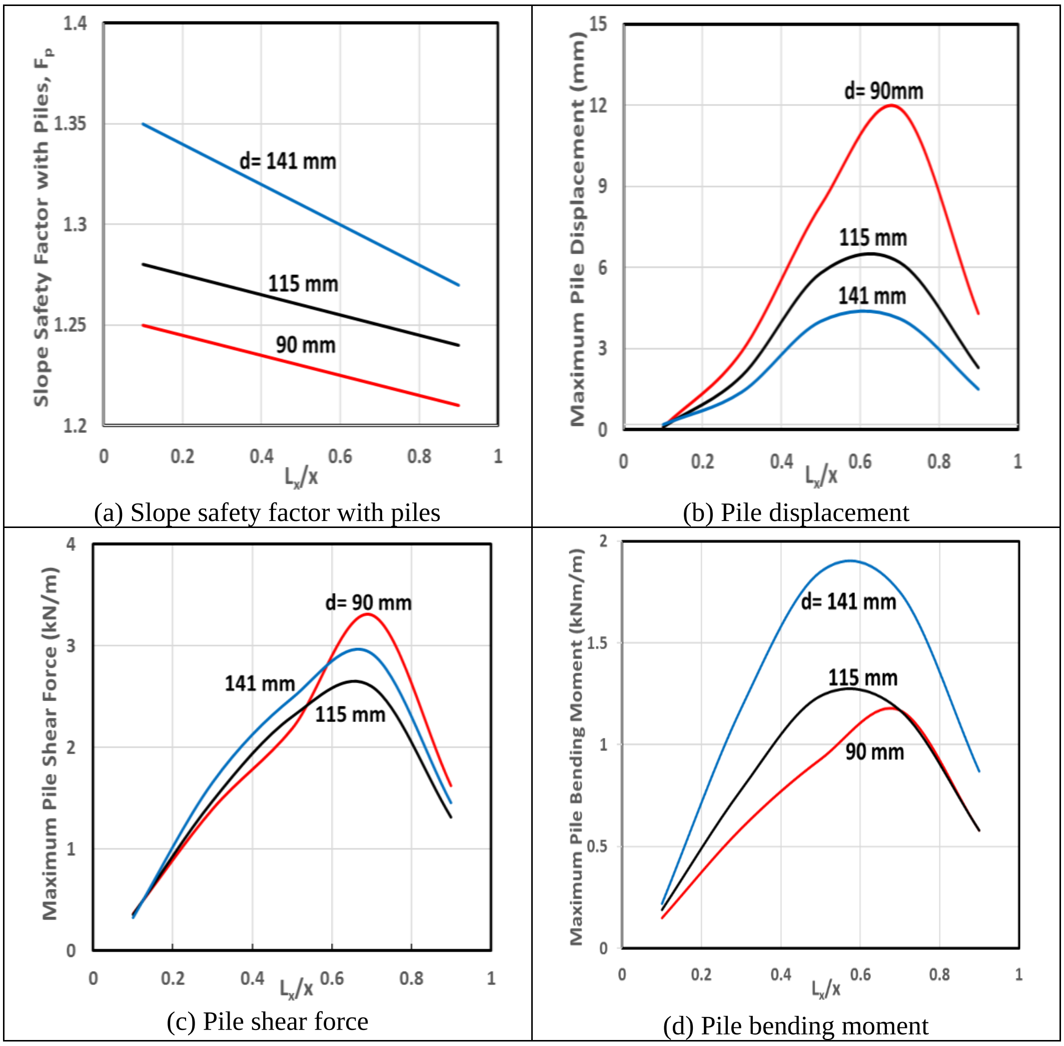

(a) Slope safety factor with piles

(b) Pile displacement

(c) Pile shear force

(d) Pile bending moment

Figure-7. Effect of pile diameter on pile-slope system (s/d=3 and 1V:1.2H)

The pile length embedded within the stable underlying slope layer will usually influence the pile behavior. In particularly, the failure mechanism will depend on the different embedded pile length. However, the small diameter steel piles used in the study are considered as flexible piles because they have length greater than its critical length. Hence, the small diameter steel pile length (L) used has negligible effect on the slope safety factor (F_p) with constant pile diameter as shown in Figure-8. It was also observed that the length of the pile increased without increase the corresponding maximum pile displacement; shear force and bending moment with constant pile diameter.

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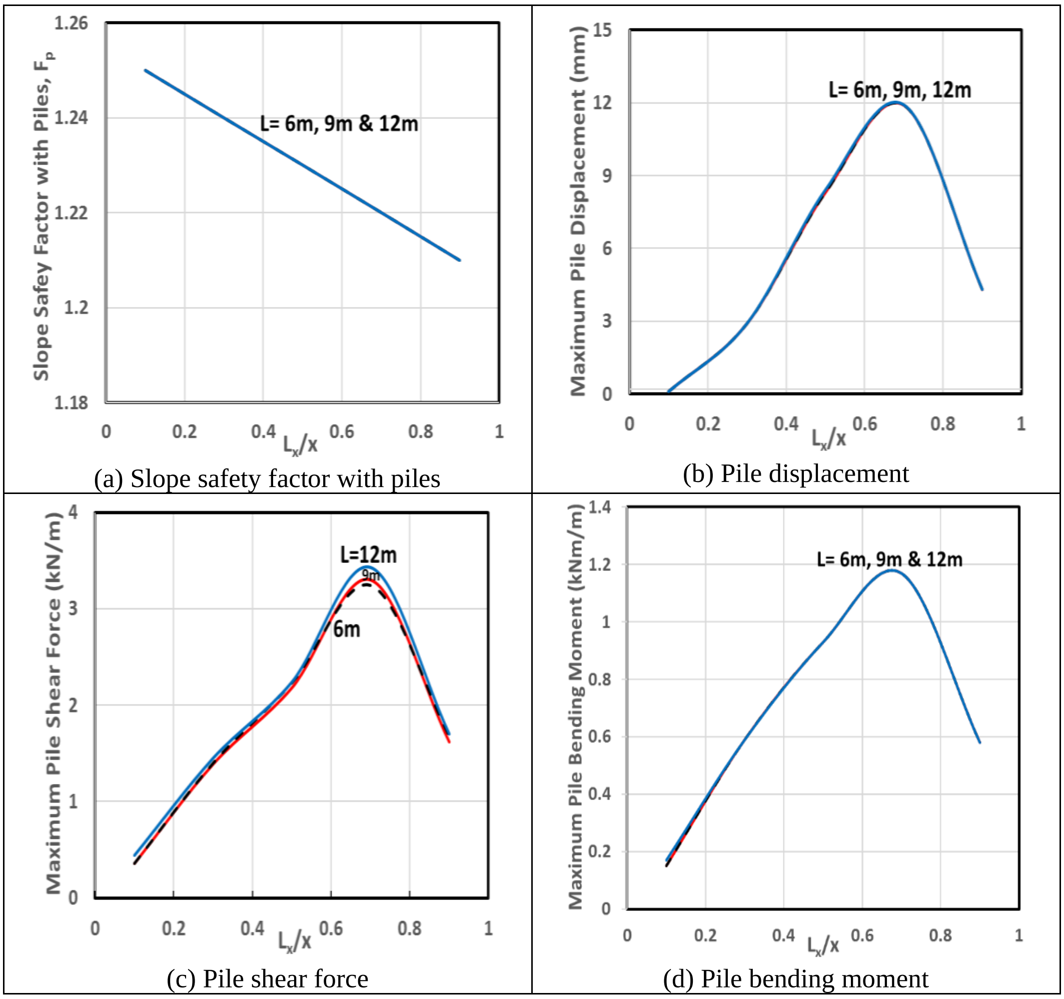

(a) Slope safety factor with piles
(b) Pile displacement
(c) Pile shear force
(d) Pile bending moment

Figure-8. Effect of pile length on pile-slope system (s/d=3 and 1V:1.2H).

CONCLUSIONS

In this paper, the parametric analysis was performed to study the effect of a row of small-diameter steel piles on the stability of the transmission tower slope using an uncoupled analysis. From the study, major influencing parameters such as soil properties, slope geometry, pile properties, position and spacing that could affect the performance of small diameter steel piles used for transmission tower slope stabilization are investigated and discussed. The numerical results show that stabilizing small-diameter steel piles can have a significant effect in improving the stability of the transmission tower slope. The safety factor of the transmission tower slope with stabilizing piles increases with increasing soil shear strength and it decreases with increasing pile spacing. The stiffer stabilizing pile with a larger diameter develops minimum displacement but a larger bending moment value and is more effective in mitigating an unstable transmission tower slope. When the stabilizing pile length used is greater than its critical length then it has negligible effect on the slope stability improvement. The study demonstrates that the parameters considered have a combined effect on the performance of small diameter steel piles to stabilize transmission tower slopes.

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REFERENCES

[1] Ito T. and Matsui T. 1975. Methods to estimate lateral force acting on stabilizing piles. Soils Found 15(4): 43-59.

[2] Viggiani C. 1981. Ultimate lateral Load on piles used to stabilize landslides. Proceedings of Xth ICSMFE, Stockholm, Sweden. 3: 555-560.

[3] Poulos H. G. 1995. Design of reinforcing piles to increase slope stability. Canadian Geotechnical Journal. 32: 808-818.

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[4] Yamin M., Liang R. Y. 2010. Limiting Equilibrium Method for Slope/Drilled Shaft System. Int. J. Num. Anal. Meth. Geomech. 1063-75.

[5] Ashour M. and Ardalan H. 2012. Analysis of Pile Slopes based on Soil-Pile Interaction. Computers and Geotechnics. 39, 85-97.

[6] Liang R. Y., Joorabchi A. E and Li. L. 2014. Analysis and design method for slope stabilization using a row of drilled shafts. Journal Geotechnical and Geoenvironmental Engineering, ASCE. 140(5).

[7] [7] Li, C., Chen, W., Song, Y. Gong, W. and Zhao, Q. (2020). Optimal location of piles in stabilizing slopes based on a simplified double-row piles model. KSCE Journal of Civil Engineering. 24: 377-389.

[8] Resende P. T. and Garcia J. R. 2021. Evaluation of the Use of Piles as a Stabilizing Element for Slope Stability. Int. Journal of Geomechanics, ASCE. 21(12).

[9] Cai F. and Ugai K. 2000. Numerical analysis of the stability of a slope reinforced with piles. Soils and Foundation, Japenese Geotechnical Society. 40(1): 73-84.

[10] Jeong S., Kim B., Won J. and Lee J. 2003. Uncoupled Analysis of Stabilizing Piles in Weathered Slopes. Computers and Geotechnics. 30(8): 671-682.

[11] Mujah D. Ahmad, F. Hazarika H. and Watanabe N. 2013. Numerical Analysis of the Multirow Arrangement of Small Diameter Steel Piles for Landslide Prevention. International Journal of Current Engineering and Technology. 3(1): 1-20.

[12] Xie X. and Wang L. Y. 2021. Study on the Influence of Micro-Steel Pipe Pile Reinforcement and Soil Structure on Landslide Stability in Geological Engineering. 6th IOP Conf. Ser.: Earth Environ. Sci. 804 022077.

[13] Benmebarek M. A., Benmebarek I. S., Rad M. M. and Ray R. 2021. Pile optimization in slope stabilization by 2D and 3D numerical analyses. Int. Journal of Geotechnical Engineering.

[14] Kontoe S., Summersgill F. C., Potts D. M. and Lee Y. S. 2022. On the effectiveness of slope-stabilising piles for soils with distinct strain-softening behaviour. Géotechnique. 72(4): 309-321.

[15] Fantera L., Lirer S., Desideri A. and Rampello S. 2022. Efficiency of Piles Stabilizing Slopes in Fine-Grained Soils. International Journal of Geomechanics. 22(9).

[16] 2020. GEO5-Slope Stability Software. Fine Ltd.

[17] 2020. GEO5-Anti-Slide Pile Software. Fine Ltd.