Kochi Chapter

Indian Geotechnical Conference
IGC 2022
15th – 17th December, 2022, Kochi

Analysis and Stabilization of Toe Excavated Slopes Using Rigid Columns

Shini S Pomson[1] and Hari G[2]

[1] PG student, Saintgits College of Engineering, Kottayam, Kerala, India
[2] Professor, Saintgits College of Engineering, Kottayam, Kerala, India
shini.gs2022@saintgits.org

Abstract. Construction activities at the toe of the slope such as excavations for road, rail and bridge construction is a leading factor to reduce the natural slope stability. Which fails when shear stress is more than the shear strength of soil slope. Thus, rigid columns can be regarded as an appealing mechanism for earth slopes stabilization with toe excavation. Furthermore, it is cost effective and simple to implement. The main objective of this study is to investigate the effectiveness of rigid columns on improving the slope stability. Using PLAXIS 3D, a finite element model of the slope and excavation at the toe of the slope with rigid column insertion is modelled. Geometric variations were carried out to investigate the potential for optimization. According to various parametric studies, embedment depth, diameter, and center to center spacing of columns are causing shift in failure mechanism. This paper presents a finite element analysis to predict the forces, displacements, and moments on columns caused by toe excavated slope. Finally, the optimal column layout is determined by the contributions of columns at various depths beneath the ground.

Keywords: Rigid column; Finite element analysis; embedment depth; optimization; failure mechanism.

1 Introduction

The slope's overall stability condition will be represented by the safety factor's weakest value. Similarly, the slope might be locally stable if a safety factor larger than one is determined along any potential slip surface that covers a particular region of the slope. A marginally stable slope requires attention, monitoring and engineering interventions like slope stabilisation techniques to minimize the possibility of a slope failure and enhance safety. The global or local marginal safety values that are close to 1 indicate this. The fundamental steps in the creation of infrastructure are soil excavation and reclamation. Therefore, managing these excavated soils that are released during building projects is a crucial factor in geotechnical engineering. Therefore, determining whether the issue is one of a certain instant or if development is the key to the study is necessary for the analysis of a slip. The stability of natural slopes is an issue that has attracted the attention of the geotechnical community up to this point. Landslide risk management and assessment of landslide risk and hazard are both becoming more and more necessary. Through a variety of analytical and approximative techniques, analyses have been used to deal with the variability of soil parameters. The shear failure mechanisms of embankment slopes and natural excavations or slopes depend on the shape of the rupture surface. In all cases, the stability calculations are carried out in short-term total stresses and in long-term effective stresses. A ground improvement technique called rigid inclusions uses columns with high deformation moduli built through compressible soils to decrease settlement and boost bearing capacity [18]. This enables the sustaining of structures on compressible soils with shallow foundations. Construction of structures may typically begin right away following ground improvement since stiff inclusions in the soil reduce settlements extremely effectively. The stiffness relationship between the soil and the columns determines how effectively the ground is improved. A load transfer platform or stiff foundation transfers the structure's load to the soil and columns.

2 Validation

The study on analysis and stabilization of toe excavated slopes using rigid columns using PLAXIS 3D as a FEM software which helps us to analyse the structure completely with field properties. In this study a toe excavated slope is considered and it was stabilized by inserting rigid columns on the sloping surface. Change in various parameters of rigid columns with respect to factor of safety deals with this study. Modelling is done for soil strata with slope and pile. For the validation of the software, PLAXIS 3D was used [4]. Here the values obtained in the literature is cross checked with laboratory results and results from our software. The model obtained from PLAXIS 3D while validating is given in Fig.1. This numerical modelling technique to study this phenomenon is the three-dimensional finite element approach, which can describe the interaction between piles and soil under lateral loads as well as the impact of slope. In this section, Plaxis3D was used to model a laterally loaded pile that was implanted close to a slope. The creation of a numerical database is the goal of this numerical modelling. Because of this, they used the experimental model to support our numerical modelling. An embedded pile in sand serves as our model with unit weight of pile as 25 $\mathrm{kN/m^3}$ and young's modulus of 35000 $\mathrm{kN/m^2}$. Its dimensions [4] are 5.0 m in length and 0.5 m in diameter. The slope H has a height of 6 metres and a 2/3 angle. According to the experimental model, the pile's flexural stiffness is 741 x 10^6 ($\mathrm{N/m^2}$).

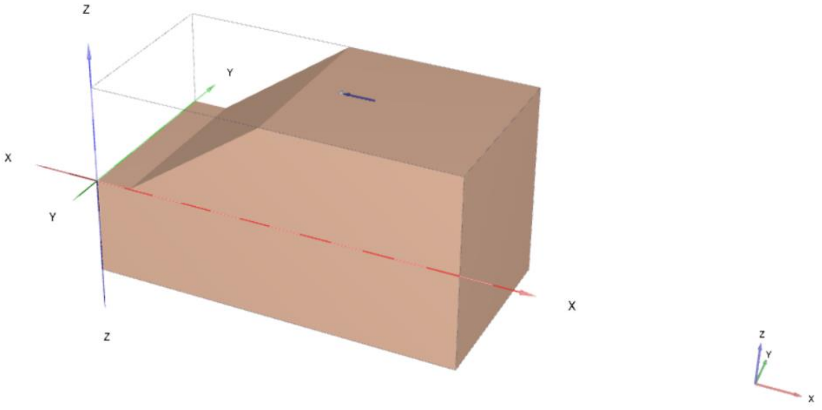

Fig.1. Model of slope in PLAXIS 3D

A similar model was simulated in PLAXIS 3D as shown in Fig.2 [4] and the results of lateral load response thus obtained was compared with that obtained by the author and that with the results obtained from laboratory were also compared using the load displacement curve.

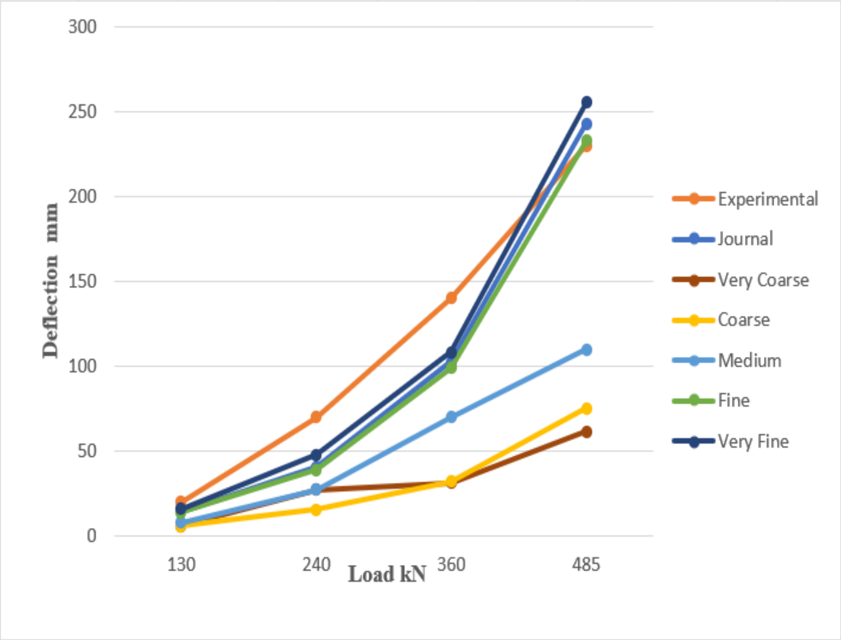

Fig.2. Correlation between the Journal, experimental and calculated

Fig.2 gives the clear idea about the results obtained during validation compared with results between journals, experiments and calculated.

3 Modelling

From a model, the work continues to obtain the result. This study consisting of total of 64 models and thus obtained the optimum result of the study conducting. Here the study is done with the help of PLAXIS 3D software, which is based on the finite element method. The obtained geotechnical properties were given as the basic properties of soil. The slope dimensions were taken as 6m x 6m at top and 10m x 6m at bottom of slope, with the height of 6 m respectively. The working load given on the top of the slope is taken as 80 kN/m^2 and the 20 kN/m^2 arround the excavation at toe. the slope angle is taken as 45^0 and the embankment dimension is taken as 12m length with 6m width and height of 3m respectively.

Table .1. Properties

PROPERTY	RESULT
Moisture Content	33.4%
Specific Gravity	2.71
Liquid Limit	64%
Plastic Limit	21%
Plasticity index	43%
Type of Soil	CH
Maximum Dry Density	1.352 g/cm^3
Optimum Moisture Content	15.87%
E_{50}	200 kPa
Angle of Internal Friction	2.67^0
Cohesion	53.4 kPa

Various geotechnical investigation on the soil sample was done at laboratory and several obtained results were tabulated on Table.1. All these tests were done based on Indian standard code. Based on these results, the next stage of project was done.

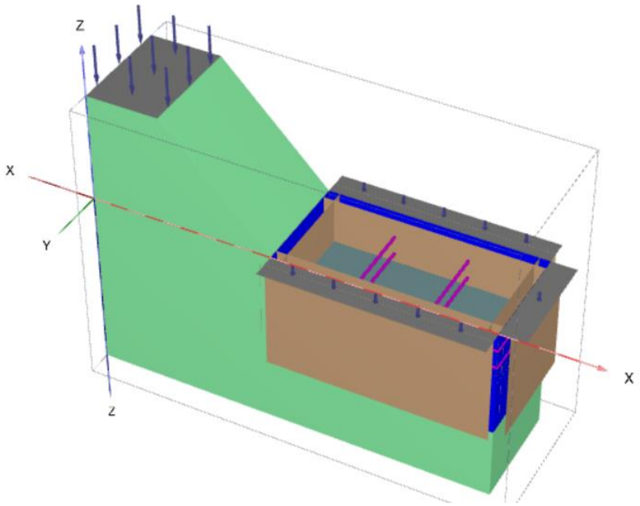

Fig.3. Model of slope with Excavation

The initial model without rigid column is given in Fig.3 above. By the introduction of rigid columns, the stability increases on a greater basis. But there arises a constraint of using of most economical number, size and dimension of rigid columns. Thus, for each selected diameter all the columns with various lengths and spacing were modelled.

3.1 Change in Diameter

Normally the rigid columns were compared with that of piles as well as with stone columns. Usually, the stone columns were having the diameter ranging from 0.8m to 1m respectively. Table.2 shows the various diameters taken for this analysis based on several studies. The piles are used to bypass the load from the structure to soil where the rigid columns are used as a reinforcing member which doesn’t transmit load directly to soil [6]. As rigid columns are not having much larger diameter, the process of installation will be easy as compared with other two.

Table.2. Change in Diameter

PARAMETER	VALUE
Diameter (m)	0.5
	0.6
	0.7
	0.8

3.2. Change in length

The columns can vary their lengths based on conditions. The variation in length was considered from 6D to 9D. Here the range of value [19] starts from 6D because, the up to this value there were not much change. Fig.4 Shows the model corresponding to rigid column with 4.2 m length and 0.5 m diameter and rigid Column with 4m length and 0.5 m diameter.

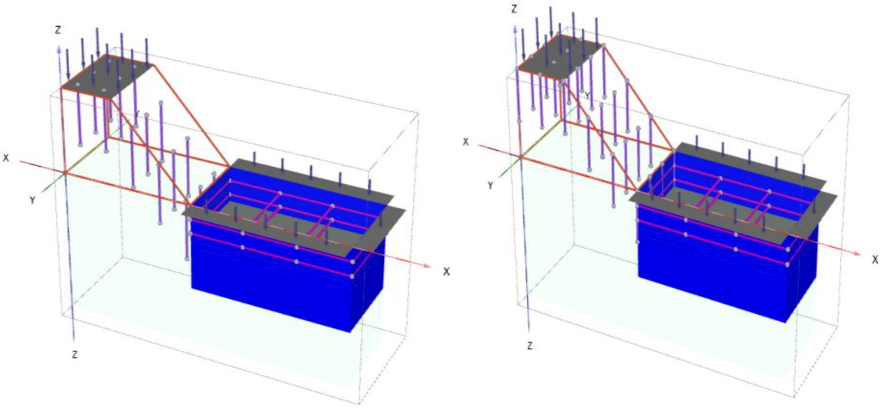

Fig.4. Rigid column with 4.2 m and 4m length

3.3. Change in Spacing

Spacing is the next factor to be noted while finding the optimal result. The spacing may vary initially from 2D to 5D, where D denotes the diameter. The change in spacing is depicted clearly in the Fig.5 and Fig.6, respectively. As the factor of safety depends on length of the columns also. Fig.7 shows the detailed plan view of model showing variation in spacing between columns.

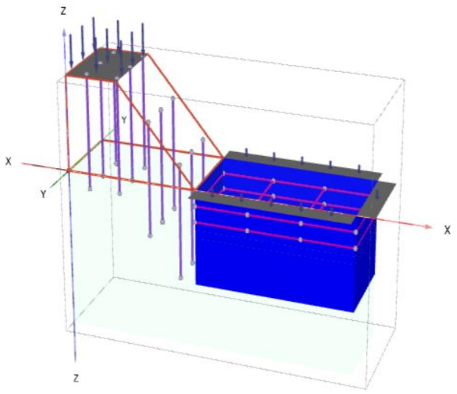

Fig.5. Rigid columns with 0.8m diameter and 7.2m length

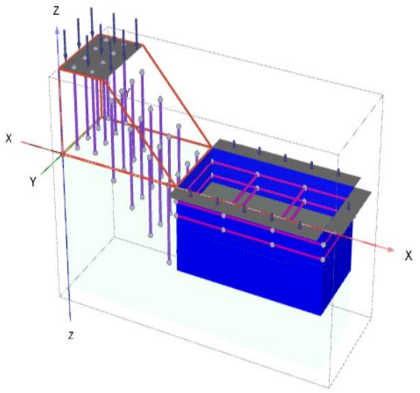

Fig.6. Rigid columns with 0.7m diameter and 5.6m length

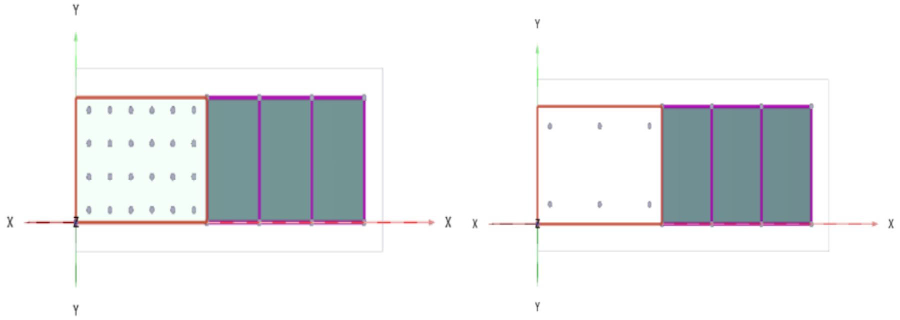

Fig.7. Spacing of 1.6m and 3m

The size of excavation chosen is 12m x 6m in plan and 3m in depth. The working loads on the soil depends on the machineries used for excavating the soil. It is simulated as a surface load of about $20kN/m^2$ in magnitude acting on the sides of the excavation. Hence there are 64 models in total with various change in parameters. Corresponding to each diameter, the length varies and for each length spacing also changes.

4 Results and Discussion

For Obtaining, the optimum value of factor of safety and analyse the overall structure with the introduction of rigid column in the slope the analysis is doing. Analysis is done at staged construction which means the construction of a project in phases, with each phase resulting in one or more structures built individually or together, regardless of whether later phases of the project are authorized. The staged construction includes the steps in which the conditions under analysis are simulated. The first phase includes the activation of soil and slope. The next phase includes activation of excavation, load on slope, working load. The further phases include activation excavation and bracing at different levels alternatively and the activation of working loads near the foundation. The final phase includes the activation of slab at the bottom of the excavation. Once staged construction is completed, the calculation can be performed, and the results can be obtained. FOS obtained corresponding to 0.5m, 0.6m, 0.7m and 0.8m diameter, in range of 64 models.

4.1 Factor of safety

Factor of safety corresponding to various parameters were found out and Fig.8 shows the variation in spacing and length corresponding to 0.5m diameter, Fig.9, Fig.10 and Fig.11 gives values corresponding to 0.6, 0.7 and 0.8m respectively.

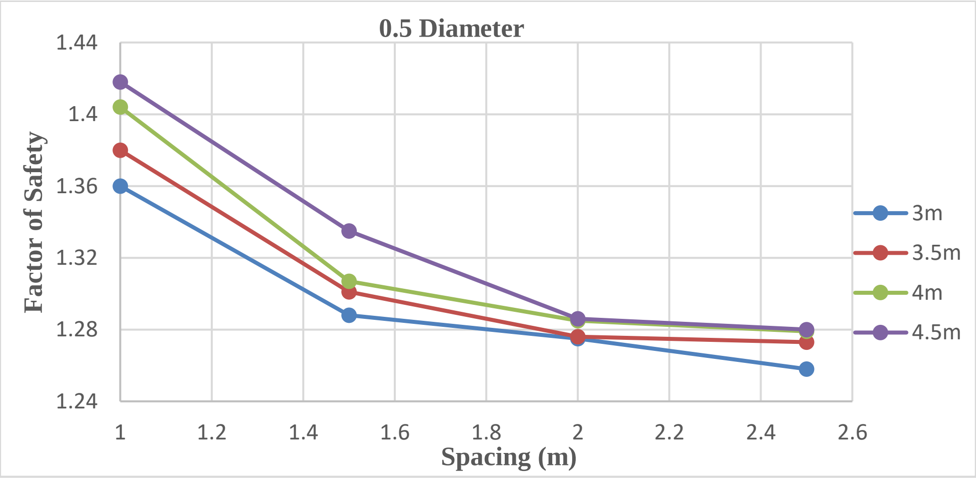

Fig.8. FOS corresponding to 0.5 m diameter

From the various graphs, it is much clear that the factor of safety increases as the spacing decreases with respect to length of columns. The increase in column diameter increases the factor of safety up to certain limit of length. This is because, as the diameter of column increases with increase in factor of safety. But with greater material requirements, the cost became concern. While reaching the length about 6.4m with diameter of 0.8m, the value of factor of safety decreases from the range of value. As the spacing also plays a role that, with lesser spacing having larger safety factor value and vice versa. According to Indian standards the factor of safety should be greater than 1 for a safer slope and maximum up to 1.5 at special conditions.

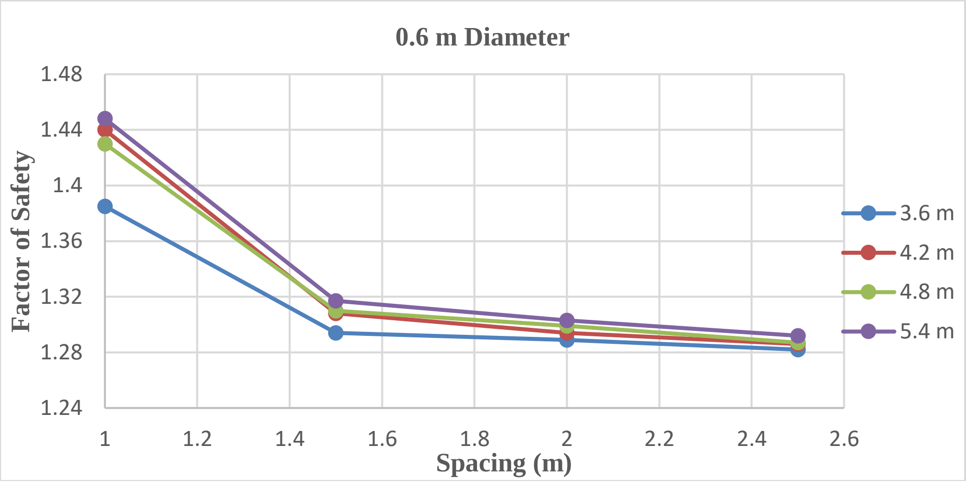

Fig.9. FOS corresponding to 0.6m diameter

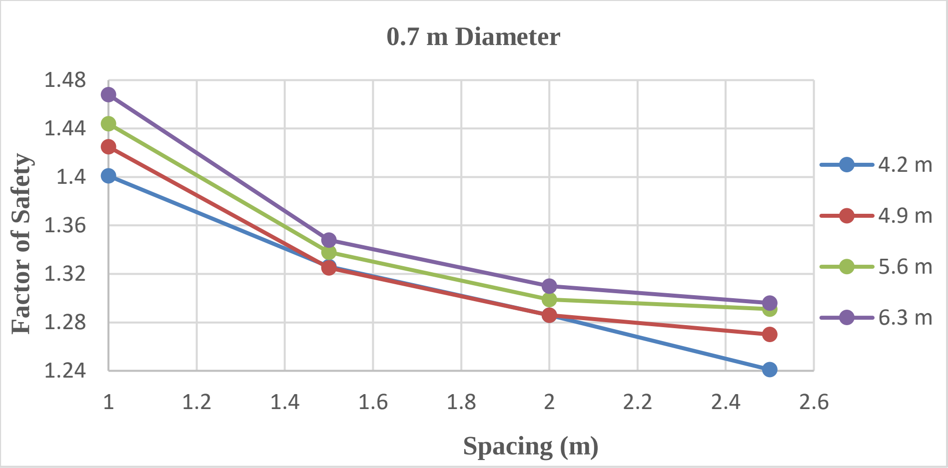

Fig.10. FOS corresponding to 0.7m diameter

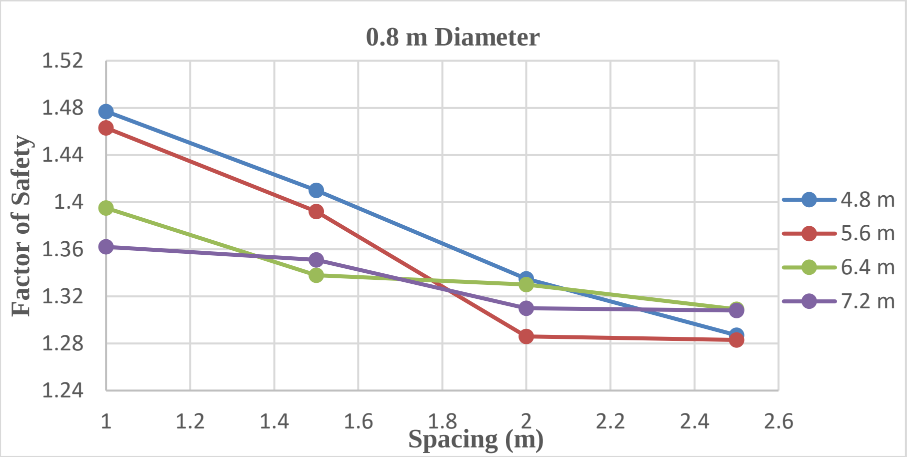

Fig.11. FOS corresponding to 0.8m diameter

5 Conclusions

Here the slope is made stable with the help of rigid columns embedded into certain depth. From various studies, it is much clear that stability can be improved with the help of this. Rigid columns were made of concrete, and it is having higher bending strength and the analysis was done with the help of PLAXIS 3D software. A detailed parametric study was held to obtain the optimal result for the practical situation. Thus, for understanding the better section from all these results, these conclusions were obtained:

- As there is an increase in column length, the factor of safety increases. And with increase in spacing, which effects the stability of the slope as such
- Factor of safety reduces, when the length of column exceeds the limit of 6.4m with column diameter of 0.8m
- At 0.8m diameter the value of FOS reduces by 4.6%. And length upto 7D, the FOS increases
- The maximum FOS obtained is about 1.477 corresponding to 0.8 m diameter with 1.6m spacing and 4.8m in length
- By introducing rigid columns, the factor of safety changes from 1.266 to 1.440 with an increase of 12%

References

1. Bouassida, M., Jellali, B., & Porbaha, A. :Limit analysis of rigid foundations on floating columns. International Journal of Geomechanics, 9(3), 89-101 (2009)
2. Choosrithong, K., Schweiger, H., & Marte, R.: Finite Element Analysis of Mixed-in-Place Columns (MIP) Supporting Excavations in Slopes Considering Tension Softening. Canadian Geotechnical Journal (2019).

3. Espada, M., Muralha, J., Lemos, J. V., Jiang, Q., Feng, X. T., Fan, Q., & Fan, Y.: Safety analysis of the left bank excavation slopes of Baihetan arch dam foundation using a discrete element model. Rock Mechanics and Rock Engineering, 51(8), 2597-2615 (2018).
4. Goudjil, K., & Arabet, L.: Assessment of deflection of pile implanted on slope by artificial neural network. Neural Computing and Applications, 33, 1091-1101 (2021).
5. Gutiérrez-Martín, A., Millán-Martín, J. P., Castedo, R., & Yenes, J. I.: Calculation of micropiles and anchors to reinforce a slope in emergency situations: application in Málaga, Spain. Geomatics, Natural Hazards and Risk, 12(1), 716-740 (2021).
6. Han, J.: Recent research and development of ground column technologies. Proceedings of the Institution of Civil Engineers-Ground Improvement, 168(4), 246-264 (2015).
7. Huang, Y., Xu, X., & Mao, W.: Numerical performance assessment of slope reinforcement using a pile-anchor structure under seismic loading. Soil Dynamics and Earthquake Engineering, 129, 105963 (2020).
8. Jamsawang, P., Voottipruex, P., Boathong, P., Mairaing, W., & Horpibulsuk, S.: Three-dimensional numerical investigation on lateral movement and factor of safety of slopes stabilized with deep cement mixing column rows. Engineering Geology, 188, 159-167 (2015).
9. Jamsawang, P., Yoobanpot, N., Thanasisathit, N., Voottipruex, P., & Jongpradist, P.: Three-dimensional numerical analysis of a DCM column-supported highway embankment. Computers and Geotechnics, 72, 42-56 (2016).
10. Jamsawang, P., Boathong, P., Mairaing, W., & Jongpradist, P.: Undrained creep failure of a drainage canal slope stabilized with deep cement mixing columns. Landslides, 13(5), 939-955 (2016).
11. Jamsawang, P., Phongphinittana, E., Voottipruex, P., Bergado, D. T., & Jongpradist, P.: Comparative performances of two-and three-dimensional analyses of soil-cement mixing columns under an embankment load. Marine Georesources & Geotechnology, 37(7), 852-869 (2019).
12. Prat, P. C.: Numerical investigation into the failure of a micropile retaining wall. Computers and Geotechnics, 81, 262-273 (2017).
13. Singh, P. K., Lahkar, H., Islary, K. V., & Goswami, D.: 3-Dimensional Slope Stability Analysis Using PLAXIS-3D. In Indian Geotechnical Conference, IIT Guwahati, India (2017).
14. Soomro, M. A., Mangnejo, D. A., Bhanbhro, R., Memon, N. A., & Memon, M. A.: 3D finite element analysis of pile responses to adjacent excavation in soft clay: Effects of different excavation depths systems relative to a floating pile. Tunnelling and Underground Space Technology, 86, 138-155 (2019).
15. Summersgill, F. C., Kontoe, S., & Potts, D. M.: Stabilisation of excavated slopes in strain-softening materials with piles. Géotechnique, 68(7), 626-639 (2018).
16. Ukritchon, B., Ouch, R., Pipatpongsa, T., & Khosravi, M. H.: Investigation of stability and failure mechanism of undercut slopes by three-dimensional finite element analysis. KSCE Journal of Civil Engineering, 22(5), 1730-1741 (2018).
17. Wang, Z. Y., Gu, D. M., & Zhang, W. G.: Influence of excavation schemes on slope stability: A DEM study. Journal of Mountain Science, 17, 1509-1522 (2020).
18. Zheng, G., Yu, X., Zhou, H., Yang, X., Guo, W., & Yang, P.: Influence of geosynthetic reinforcement on the stability of an embankment with rigid columns

embedded in an inclined underlying stratum. Geotextiles and Geomembranes, 49(1), 180-187(2021).

19. Zhou, H., Zheng, G., Liu, J., Yu, X., Yang, X., & Zhang, T.: Performance of embankments with rigid columns embedded in an inclined underlying stratum: centrifuge and numerical modelling. Acta Geotechnica, 14(5), 1571-1584 (2019).
20. Zhu, C., He, M., Karakus, M., Cui, X., & Tao, Z.: Investigating toppling failure mechanism of anti-dip layered slope due to excavation by physical modelling. Rock Mechanics and Rock Engineering, 53(11), 5029-5050 (2020).