# Numerical Analysis of the Effect of Creep on the Settlement and Failure Pattern of Helical Piles Foundations

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## ABSTRACT

Peat soil is a unique type of soft soil that has a low bearing capacity and experiences significant creep effect. This inherent challenge necessitates effective improvement methods to enhance its stability, among which helical pile foundations stand out as a viable solution. Despite their promising application, the nuances of how creep influences the performance of these helical piles in peat soil remain largely unexplored. This study aims to analyse the effect of creep on the settlement and failure pattern of helical pile foundations in peat soils. Axis-symmetric two-dimensional numerical analyses using the finite element method were carried out to model helical piles foundations with varying creep indices ($C\alpha$) and differing spacings between the helical plates (1D and 3,5D). The results showed that the effect of creep caused the settlement of helical piles to increase as the value of $C\alpha$ increases. However, the changes of excess pore water pressure around the helical pile foundation were not significantly affected by the variation of $C\alpha$ value. In addition, the failure patterns of helical piles foundations were not affected by the creep effect, with the failure mechanism still following the cylindrical shear pattern for the 1D inter-plate spacing and the individual bearing pattern for the 3,5D inter-plate spacing. This study provides insight into the importance of considering the effect of creep in the design of helical piles foundations in peat soils for long term use.

**Keywords:** peat soil, helical piles foundations, creep effect, numerical analysis, finite element, failure pattern

## INTRODUCTION

Peat soil is a type of soft soil that has a low bearing capacity so that it cannot withstand loads without experiencing large deformations. The general characteristics of peat soils include a high organic content (>75%), high moisture content (100% - 1500%), very high compressibility, and low bearing capacity [1]. Peat soil formation is attributed to a mixture of fragments of organic material derived from plants that have decayed and become fossils [2]. The prevalence of peat soils in Indonesia is well documented, with their presence being notable on large islands such as Sumatra, Kalimantan and Papua [3].

However, due to their inherently low load-bearing capacity, the construction of buildings on peat soils requires measures to enhance the shear strength of the peat soil or to reinforce it with alternative foundation types that can increase the bearing capacity of the foundation. Typically, pile foundations are utilised in such constructions, penetrating the hard soil layer below the peat soil layer, for example as stated by [4]. Nevertheless, the cost of employing pile foundations to reach hard ground can be substantial, particularly in cases where the peat layer is substantial in thickness. One alternative type of foundation in peat soils that can increase load bearing capacity is a helical pile foundation [5].

Helical piles consist of one or more helical plates, which are fabricated steel elements that facilitate the installation process by rotating them into the ground [6]. The basic components of a helical pile, including the piers, helical bearing plates (spiral plates), and pile heads, are detailed in Figure 1.

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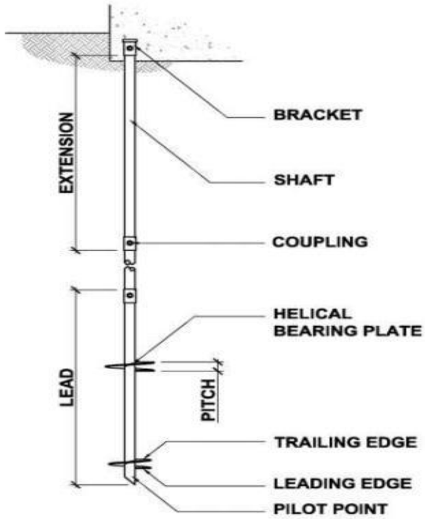


**Figure 1**. Helical pile components [7]

The installation process of helical pile foundations is simple, fast, and efficient. When installing a helical pile, construction experts utilise a hydraulic machine to rotate the pile in a clockwise direction. Conversely, when the helical pile is to be pulled out, the workers merely rotate the pile in an anti-clockwise direction. A notable advantage of helical piles installation is its independence from undesirable side effects such as vibration and noise as in the driven pile method and water or soil waste as in the drilled pile method.

The studies conducted by [8], [9] demonstrate a significant increase in the bearing capacity of helical piles foundations compared to conventional pile foundations. This enhancement in bearing capacity for helical piles foundations is attributed to the contribution of resistance provided by the helical plates in peat soil. The bearing capacity of helical piles foundations can be analysed based on the failure patterns of the helical piles, specifically through the mechanisms of individual bearing and cylindrical shear [7]. In the case of the spacing between the helical plates is relatively large, each plate functions independently, and the total bearing capacity is the sum of the individual bearing capacities of all helical plates. This mechanism is referred to as the individual bearing mechanism. Conversely, when the spacing between the helical plates is small, the plates and the soil in between act as a unified cylinder, and the bearing capacity is a combination of the bearing resistance of the lowest helical plate and the shear forces of the soil side between the plates. This latter scenario is identified as the cylindrical shear mechanism.

Creep is a phenomenon characterized by continuous deformation under sustained load conditions. Peat soil exhibits a relatively significant creep effect [10]. Over the long term, peat soil continues to undergo deformation even when the applied load remains constant. The influence of creep on the deformation response and the failure patterns or mechanisms of helical piles foundations remains poorly understood, to the best of current knowledge. Therefore, this study aims to investigate and analyse the effects of creep on the settlement response and failure patterns of helical pile foundations over an extended period or long-term duration following construction.

## RESEARCH METHODS

This research was conducted using geotechnical numerical analysis employing the finite element method. However, this numerical analysis was based on the physical model study of helical pile foundations previously conducted by [8]. The numerical modelling utilized axisymmetric geometries, which were employed to model the helical piles foundations in a circular configuration based on polar coordinates. The typical geometric model and finite element mesh that are used in the numerical analysis of the helical piles foundations can be observed in Figure 2.

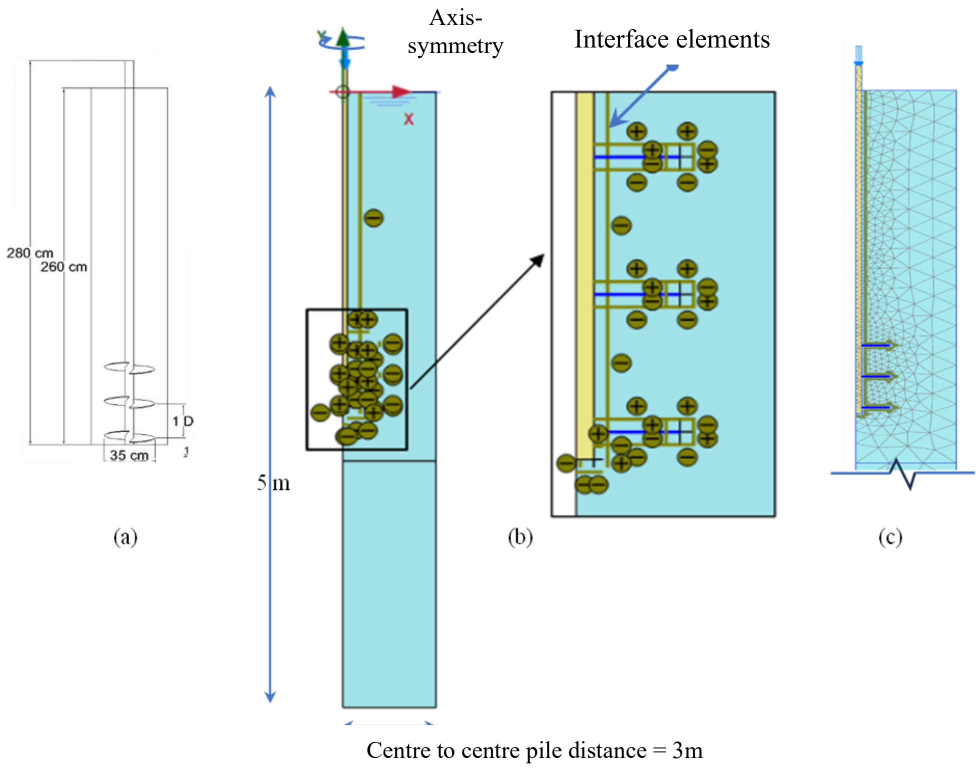


**Figure 2.** Numerical modelling of the helical piles foundations; (a) Helical pile foundation with an inter-helical plate spacing of 1D, (b) Axisymmetric model of the helical pile foundation, (c) Typical Finite element mesh that is used in the analysis.

The two-dimensional axisymmetric geometry model of the helical piles foundation has a height of 5 meters and a width equivalent to half of three times the diameter of the helical plate (D), which is 0,525 meters. The groundwater table is located at the surface of the peat soil. The finite element mesh used, as illustrated in Figure 2c, consists of 15 nodes triangular elements. Approximately 1050 elements were employed, with an average element size of 0,06 meters. Interface elements were applied along the contact between the pile, helical plates, and the peat soil. The use of interface elements has been recommended by several researchers, such as [11] and [12], to prevent the occurrence of excessively large and unrealistic stress distributions, particularly at sharp edges such as the tips of the helical plates.

In order to model the effect of creep, commonly referred to as viscous effect in peat soil, the Soft Soil Creep constitutive model is employed. As for comparison, the Soft Soil model is also utilised, which is designed to analyse soft soil without incorporating the effect of creep. Consequently, the soil parameters used in the Soft Soil Creep and Soft Soil models are nearly identical. However, the Soft Soil model does not incorporate the creep index parameter (Cα). The peat soil material parameters used in this numerical analysis are presented in Table 1. The data were derived from the study conducted by [8], [13].

**Table 1**. Peat soil parameters for finite elements calculations

| No. | Parameter | Notation | Value | Unit |
|---|---|---|---|---|
| | Material Model | *Soft Soil Creep/ Soft Soil* | | |
| 1. | Saturated Unit Weight | $\gamma_{sat}$ | 10,75 | [kN/m$^3$] |
| 2. | Unsaturated Unit Weight | $\gamma_{unsat}$ | 10,75 | [kN/m$^3$] |
| 3. | Initial Void Ratio | $e_{int}$ | 16,86 | [-] |
| 4. | Compression Index | *Cc* | 7,5 | [-] |
| 5. | Swelling index | *Cs* | 0,75 | [-] |

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| No. | Parameter | Notation | Value | Unit |
|---|---|---|---|---|
| 6. | Creep Index | $C\alpha$ | Bervariasi | [-] |
| 7. | Cohesion | $c'$ | 3 | [kN/m$^2$] |
| 8. | Friction Angle | $\phi'$ | 44 | [°] |
| 9. | Dilatation Angle | $\psi$ | 0 | [°] |
| 10. | Poisson's ratio for unloading-reloading | $\nu'_{ur}$ | 0,3 | [-] |
| 11. | $R_{inter}$ | | 0,75 | [-] |
| 12. | Drainage type | | Undrained | |

To analyse the influence of creep intensity on helical piles foundations, several values of the creep index (Cα) were utilized in this study. Naturally, as an initial estimate, the creep index typically varies within the range of approximately Cc/25 to Cc/15 (Brinkgreve, 2016). However, for peat soils, the creep index can exceed these estimates. Therefore, this study employed five variations of the creep index (Cα) as follows:

a. Cα = Cc/30 = 7,5/30 = 0,250

b. Cα = Cc/25 = 7,5/25 = 0,300

c. Cα = Cc/20 = 7,5/20 = 0,375

d. Cα = Cc/15 = 7,5/15 = 0,500

e. Cα = Cc/10 = 7,5/10 = 0,750

In addition to the variation in the creep index, the numerical analysis of the helical piles foundations was also conducted using two different inter-helical plate spacings: 1D and 3,5D. The use of two types of analyses with different inter-helical plate spacings was aimed at examining the creep effects on two distinct failure patterns. This approach is based on the findings of [14], which indicates that helical piles tend to exhibit a cylindrical shear failure pattern when the inter-helical plate spacing is less than or equal to 2,5D, while an individual bearing failure pattern is observed when the inter-helical plate spacing is equal to or larger than 2,5D. Other researchers, such as [15], [16] and [7], have similarly noted that helical pile foundations are more likely to follow a cylindrical shear failure pattern if the inter-helical spacing is less than or equal to 3D.

The pile shaft modelled in this analysis has a diameter of 0,06 meters, a total length of 2,8 meters, and an embedded length of 2,6 meters. The pile was modelled as a linear elastic material. The parameters used for the helical pile material model are presented in Table 2. The helical plates were modelled as elastic structural plates.

**Table 2**. Pile shaft parameters

| No | Parameter | Notasi | Nilai | Satuan |
|---|---|---|---|---|
| 1. | Unit Weight | $\gamma_{pile}$ | 19,17 | [kN/m$^3$] |
| 2. | Young's Modulus | E | 2 x 108 | [kN/m$^2$] |
| 3. | Poisson's Ratio | ν | 0,3 | |

The numerical analysis of the helical piles foundations is divided into four computational stages. The first stage is the initial phase, during which the in-situ stresses of the soil and initial pore water pressure prior to pile installation are re-established according to field conditions. The subsequent stage involves the installation of the helical pile, which is simulated directly and has not considered the effects of installation process (wished-in-place). Following this, the loading stage is conducted, wherein a uniformly distributed vertical load of 601,3 kN/m/m is applied to the top of the pile head. This stage is succeeded by the consolidation phase, which is carried out incrementally over periods of 3 days, 7 days, 14 days, 30 days, 3 months, 6 months, 1 year, and up to 10 years.

## RESULT AND DISCUSSION

The results of the numerical analysis of the helical piles foundations are presented in two parts: an analysis of the creep effect on the helical piles foundations with an inter-helical plate spacing of 1D and an inter-helical plate spacing of 3,5D. The analysis of the numerical calculation outputs focusses on the settlement of the helical piles foundations and the variation of excess pore water pressure over time. In addition, evaluations are conducted on the total displacements and the mobilized shear strength of the peat soil.

**Creep Effect on Helical Piles Foundations with Inter-Helical Plate Spacing of 1D**

The settlement of the helical pile due to creep effect increases proportionally with the increase in the creep index (Cα). Figure 3 illustrates the settlements of helical pile head over time, considering various creep index variations. The line labelled "Soft Soil" represents the settlement of the helical pile head without the influence of creep. From the graph, it can be observed that, without the creep effect, the settlement of the helical pile head ceases at approximately 200 days. This also indicates that the consolidation process (dissipation of excess pore water pressure) is completed by that time. However, when creep effect is considered, the settlement of the pile head continues, although with diminishing intensity over time.

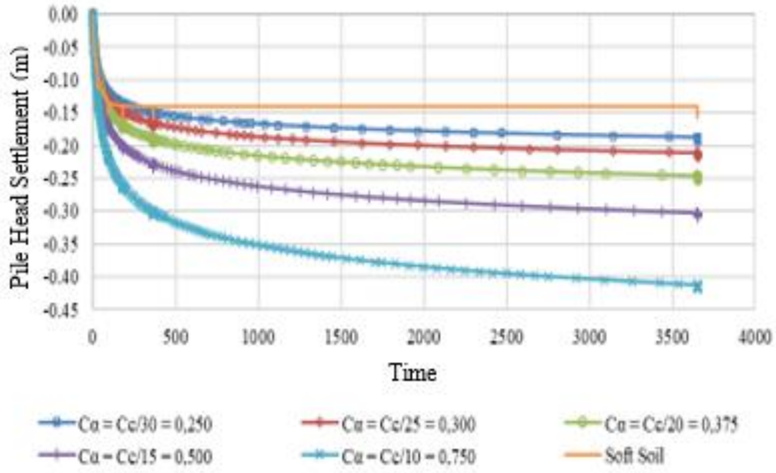


**Figure 3**. Pile head settlement with time for inter-helical plate spacing of 1D

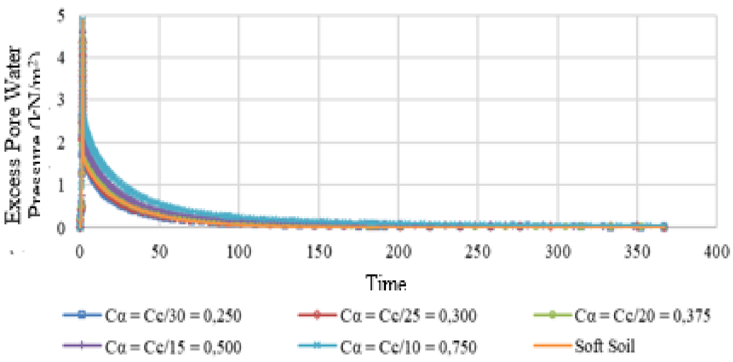


**Figure 4**. Changes in excess pore water pressure below the bottom plate with time for inter-helical plate spacing of 1D

Figure 4 presents the values of excess pore water pressure at the base of the lowest helical plate over a one-year consolidation period. The figure indicates that the excess pore water pressure slightly increases with higher values of the creep index parameter (Cα). However, this increase is not significant. The excess pore water pressure rises initially upon loading and subsequently decreases or dissipates over time. The excess pore water pressure is fully dissipated within approximately 200

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days. This observation aligns with Figure 3, which demonstrates that consolidation settlement also concludes within the same timeframe.

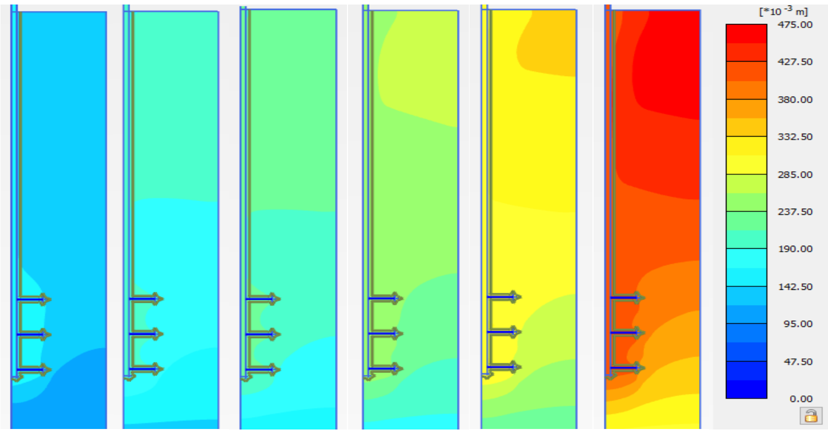


**Figure 5**. Total displacement contours after 10 years consolidation time for inter-helical plate spacing of 1D

The contour plots of total displacements, obtained after the 10-year consolidation calculation phase, is illustrated in Figure 5. The graphs indicate that the intensity of total displacements around the helical pile increases with higher values of the creep index (Cα). Additionally, larger values of Cα result in more non-uniform settlement of the pile and the surrounding peat soil, although, in general, the settlement of the pile and the adjacent soil tends to form a unified block. Consequently, as the creep effect intensifies, the peat soil surface and the helical pile experience greater settlement, thereby reducing the block mechanism (uniformity of settlement between the peat soil and the helical pile).

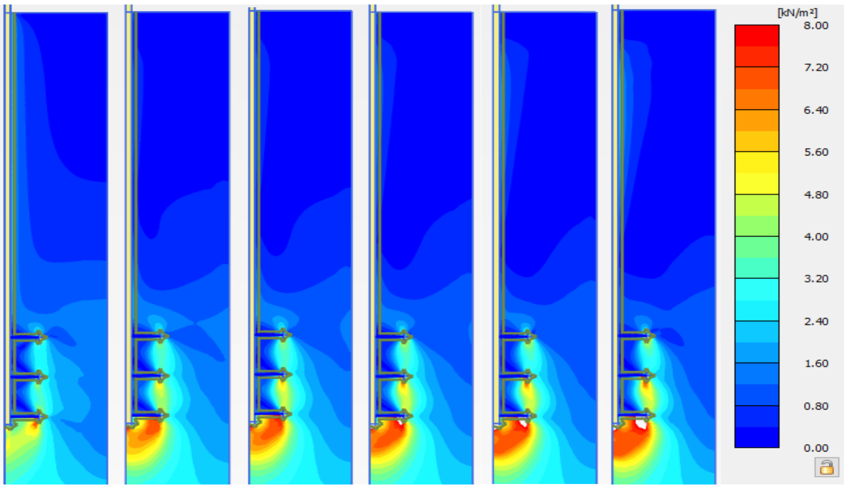


**Figure 6**. Mobilized shear strength contours for inter-helical plate spacing of 1D

The failure mechanism of the helical piles foundations can be analysed through the contour output of the mobilized shear strength of the soil. Figure 6 displays the contour results of the mobilized shear strength in the peat soil surrounding the helical plates. The failure mechanism of the helical pile foundation with an inter-plate spacing of 1D, as depicted in the contour outputs in Figure 6, follows a cylindrical shear mechanism. This is evident from the nearly uniform and interconnected distribution of mobilized shear strength around the helical plates, indicating that soil failure around the helical plates forms a cylindrical shape.

When examining the mobilized shear strength contours with creep effect represented by different values of Cα, all contour outputs for varying Cα values exhibit nearly identical patterns. Therefore, the intensity of creep does not significantly influence the failure mechanism of the helical piles foundations.

### Creep Effect on Helical Piles Foundations with Inter-Plate Spacing of 3.5D

The settlement response of the helical piles foundations with an inter-plate spacing of 3.5D is nearly identical to that of the helical pile foundation with an inter-plate spacing of 1D. The settlement of the helical pile due to creep effect increases proportionally with higher values of the creep index (Cα). Figure 7 illustrates the settlement of the helical pile head with time for various creep index values. The line labelled "Soft Soil" represents the settlement of the helical pile head without the influence of creep. From the graph, it can be observed that, in the absence of creep effect, the settlement of the helical pile head ceases at approximately 200 days. This suggests that the consolidation process (dissipation of excess pore water pressure) is likely completed by that time. When creep effect is considered, the settlement of the pile head continues, even though with decreasing intensity over time. Compared to the settlement responses of the helical piles foundations with an inter-plate spacing of 1D, the settlement responses of the foundations with an inter-plate spacing of 3.5D are slightly greater.

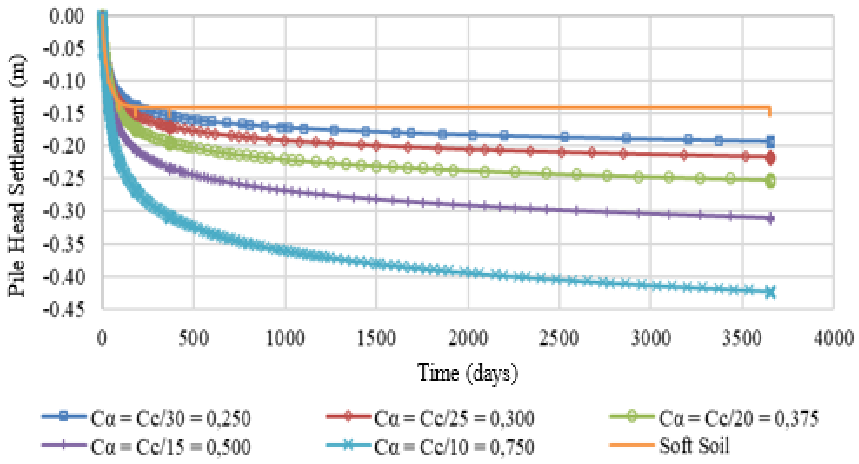


**Figure 7**. Pile head settlement with time for inter-helical plate spacing of 3,5D

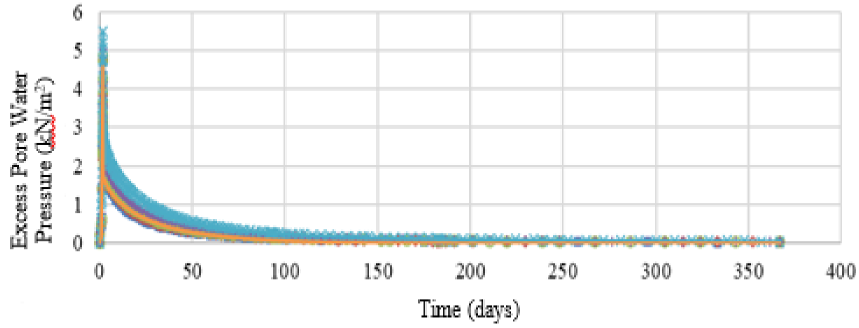


**Figure 8**. Changes in excess pore water pressure below the bottom plate with time for inter-helical plate spacing of 3,5D

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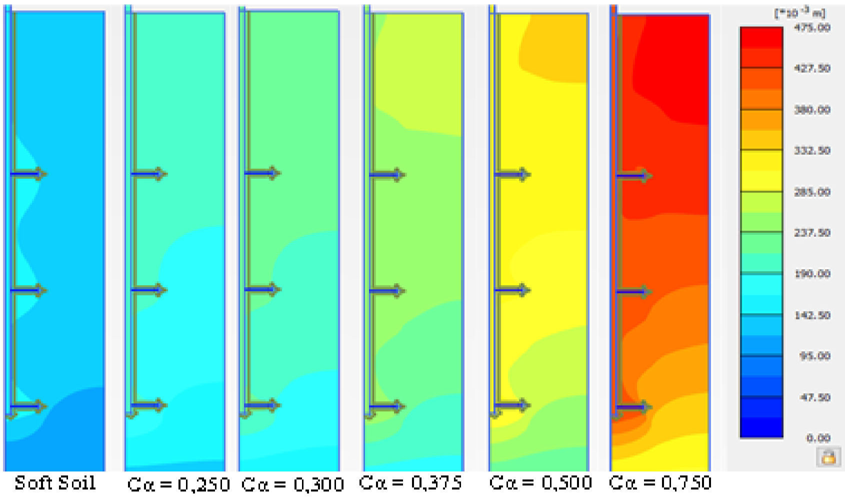


**Figure 9**. Total displacement contours after 10 years consolidation time for inter-helical plate spacing of 3,5D

Figure 8 illustrates the values of excess pore water pressure occurring beneath the lowest helical plate over the course of one year of consolidation for an inter-plate spacing of 3.5D. The response of the excess pore water pressure variation is similar to that observed for the inter-plate spacing of 1D. The excess pore water pressure slightly increases with higher values of the creep index parameter (Cα), although this increase is not significant. The excess pore water pressure rises initially upon loading and subsequently decreases over time. The excess pore water pressure is fully dissipated within approximately 200 days.

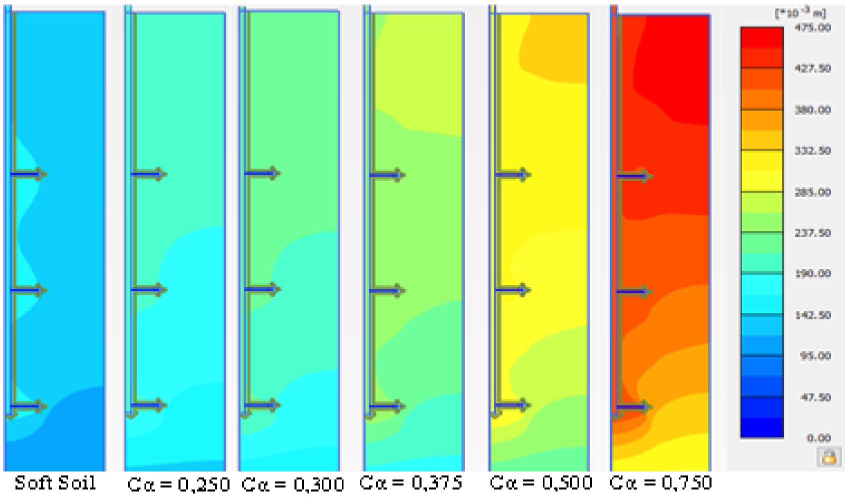


Figure **9** presents the contour plots of total displacements resulting from the consolidation process over a period of 10 years. The graphs indicate that the intensity of total displacements around the helical pile increase with higher values of Cα. Furthermore, an increase in Cα leads to more uneven settlements of both the pile and the surrounding peat soil. Although, in general, the settlements of the soil and helical pile tend to form a uniform (block) pattern, the greater creep effect causes a more significant settlement of the surface peat soil and the helical pile, thereby reducing the block mechanism (uniform settlement).

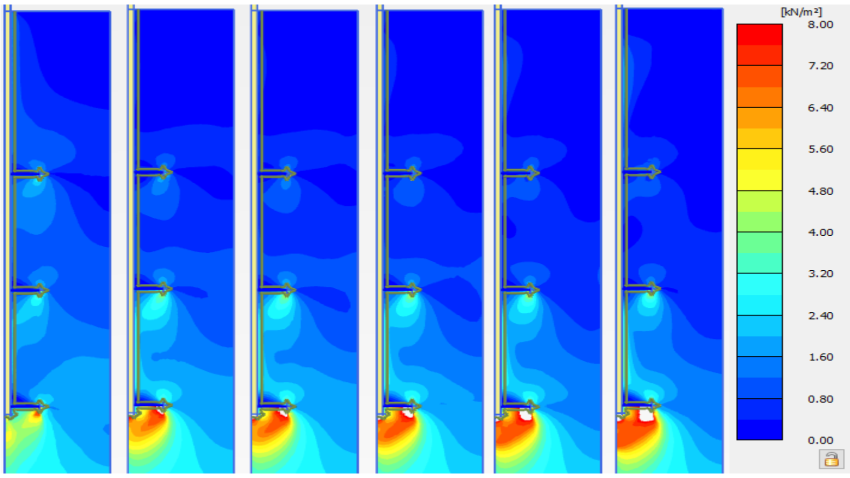


**Figure 10**. Mobilized shear strength contours for inter-helical plate spacing of 3,5D

Figure 10 illustrates the contour distributions of mobilized shear strength in the peat soil surrounding the helical plates, with an inter-plate spacing of 3.5D. The observed failure patterns of the helical piles foundations suggest individual bearing failure mechanism. This is evident from the concentration of mobilized soil shear strength around each plate without any apparent connection between the helical plates, indicating that each plate operates independently.

When analysing the contour patterns of mobilized shear strength under the influence of creep effect, represented by the Cα value, the results for various Cα values exhibit a nearly identical pattern. Thus, the intensity of the creep effect does not significantly influence the failure pattern of the helical piles foundations.

## CONCLUSION

Based on the numerical analysis of creep effect on the settlement response and failure pattern of helical piles foundations in peat soil using the finite element method, the following conclusions can be drawn. The creep index (Cα), which represents the intensity of creep, significantly influences the settlement of helical piles foundations, where an increase in Cα leads to more pronounced foundation settlement. This finding indicates that creep effect plays a substantial role in the deformation process of the soil surrounding helical piles foundations, particularly over long-term periods. However, the creep index (Cα) does not have a significant impact on changes in excess pore water pressure around the helical pile foundation. The observed variations in excess pore pressure remain relatively unchanged and do not exhibit a strong correlation with different Cα values. Furthermore, the analysis reveals that the failure pattern of helical piles foundations is not affected by variations in Cα. The failure mechanism remains consistent, indicating that creep effect do not influence the distribution of mobilized shear strength or the interaction pattern between the helical plates and the surrounding peat soil.

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