Numerical Simulation Study of Geotextiles Free-End Anchorage Pullout Tests

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Abstract. This study involves the numerical simulation analysis of geotextile pullout tests, followed by a comparison with the pullout test results to establish the reliability of the numerical simulation calculation model. Subsequently, the study primarily investigates the impact of various parameters, including the free-end wrapping height, wrapping length, normal pressure, geotextile laying length, and selected soil properties on the pullout force when geotextiles are wrapped at their free ends. The numerical simulation results indicate that, compared to the non-wrapped scenario, the adoption of end wrapping for geotextiles significantly enhances the pullout force. However, the pullout force is only minimally affected by the length and height of the end wrapping. The numerical simulation research reveals that as the geotextile laying length increases, the rate of pullout force enhancement with end wrapping compared to non-wrapping becomes progressively slower. Hence, under appropriate conditions of wrapping height, length, and geotextile flat placement length, the highest efficiency in pull-out force enhancement is achieved when the wrapping method is employed at the free end of the reinforcement material.

Keywords: Geotextiles, pullout testing, numerical simulation, wrapping

1 Introduction

Geotextiles are widely used in roads, railways, and hydraulic engineering. The free-end anchorage pullout test is a common method for evaluating the mechanical properties of geotextiles. The method of analyzing test results through the establishment of numerical simulation models using finite element software has gained significant traction in the international geotechnical engineering domain. Researchers, both domestically and abroad, have already undertaken considerable studies on the role of geotextiles and numerical simulation experiments.

Regarding investigations into the function of geotextiles, Li Xiao [1] revealed the anchoring mechanisms during the free-end wrapping of geotextiles by combining reduced-scale model tests of actual subsidence engineering. Audrey Huckert and others

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[2] studied the load transfer mechanism in the voids overlying geotextile-reinforced embankments through experiments and analysis.

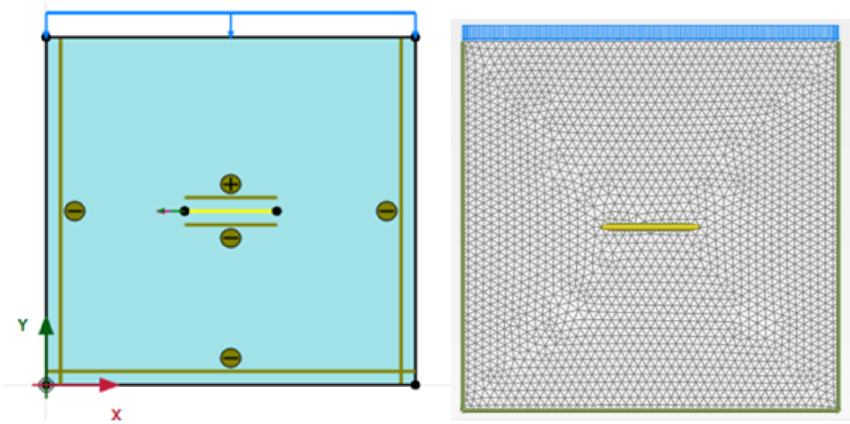
In the realm of numerical simulation research on geotextiles, Chungsik Yoo [3] conducted parameter studies using a three-dimensional finite element model on factors such as the thickness and density of soft soil foundations, the length and stiffness of geosynthetic wrap materials, the height of embankment fill, and the area replacement ratio. Su Lei and his team [4] explored the influence of geotextile layout and cyclic strain amplitude on the liquefaction behavior of saturated sandy soil. Shao Lipan et al. [5] established finite element models through numerical simulation analysis to assess the effects and mechanisms of reinforced geotextiles on embankments. Tan Xin and his colleagues conducted numerical simulations of single-axis and triaxial compression tests on geotextile-wrapped gravel piles, validating the rationality of the numerical model through comparative test data and analyzing the effects of geotextile modulus, tensile strength, and confining pressure on the mechanical properties of wrapped gravel piles.

In summary, recent studies on geotextiles have increasingly favored numerical simulation methods over experim

2 Finite Element Analysis Introduction

2.1 Establishment of Finite Element Model

For this experiment, we established a numerical analysis model with dimensions of 400mm × 400mm based on the pullout test model box size, as depicted in Figure 1. The model employs a mesh type consisting of 15-node high-precision triangular elements, with the soil structure characterized by the Mohr-Coulomb model. Geotextile interactions are simulated using the geogrid elements provided by PLAXIS 2D. The model's lateral boundaries are subject to horizontal constraints, while the bottom boundary is set with fixed constraints. At the top of the model, a uniformly distributed load is applied to simulate the normal pressure, and the pullout displacement is established using a predefined displacement method. To model the interface between the geotextile and the soil, we employed the interface elements provided by PLAXIS 2D, with a coefficient of 0.9 representing the interaction between the geotextile and soil at the interface. In the numerical simulation process, the soil and geotextile are initially activated to initiate contact, followed by the activation of uniformly distributed loads applied to the top of the soil and predefined displacements. It's important to note that all aspects of this model are configured above the groundwater level.



(a)Numerical model (b)Grid division diagram

Fig. 1. Numerical model schematic

2.2 Material Parameter Selection

For the numerical model experiments, we employed the Mohr-Coulomb model provided by the PLAXIS 2D software for the fill material. This model encompasses five key parameters: Young's modulus (E), Poisson's ratio (v), cohesion (c), internal friction angle (φ), and dilatancy angle (Ψ). The material parameters were obtained through standard geotechnical testing, ensuring consistency with the parameters used in the pullout tests. Specific physical and mechanical properties can be found in Table 1.

Table 1. Simulation parameters of packing

Material type	Material modeling	Modulus of elasticity /MPa	Poisson's ratio	Cohesion /kPa	Angle of internal Friction /°	Strength reduction factor
sandy soil	Moore Cullen	30	0.3	0.15	34.5	0.9

2.3 Model Validation

In order to verify the reliability of the numerical computational model, it is imperative to perform a comparative analysis between the model test and numerical simulation test results. Standard sand was employed as the fill material in the pull-out test, and the testing procedure utilized the Multi-Functional Geosynthetic Material Tensile Testing Machine (referred to as MGT1000) to conduct conventional pull-out tests on two reinforced materials, namely, woven and non-woven geotextiles, as outlined in Table 2.

Table 2. Experimental model plan

Normal stress P/kPa	Specimen dimensions mm×mm	Flat placement length L/mm	Wrapping height h/mm	Wrapping length d/mm	Number of test groups
25	200×200	100	0	0	2
50	200×200	100	0	0	2
75	200×200	100	0	0	2
100	200×200	100	0	0	2
25	200×200	100	100	100	2
50	200×200	100	100	100	2
75	200×200	100	100	100	2
100	200×200	100	100	100	2

Through the utilization of finite element software and the selection of appropriate numerical simulation parameters, the pull-out test was subjected to numerical simulation. The specific configuration of the numerical simulation experiment is detailed in Table 3.

Table 3. Numerical simulation experiment plan

Normal stress P/kPa	Pull-out displacement l/mm	Flat placement length L/mm	Wrapping height h/mm	Wrapping length d/mm	Number of test groups
50	--	100	0	50	2
50	--	100	5	50	2
50	--	100	10	50	2
50	--	100	30	50	2
50	--	100	50	50	2
50	--	100	70	50	2
50	--	100	100	50	2
50	--	100	150	50	2
50	--	100	10	0	2
50	--	100	10	5	2
50	--	100	10	10	2
50	--	100	10	30	2
50	--	100	10	50	2
50	--	100	10	70	2
50	--	100	10	100	2
50	--	100	10	150	2
50	50	50	10	50	2
50	50	100	10	50	2
50	50	150	10	50	2

50	50	200	10	50	2
50	50	50	10	50	2
50	50	100	10	50	2
50	50	150	10	50	2
50	50	200	10	50	2

The data collection and processing system was utilized to gather, record, and process relevant data obtained during the pullout tests. Subsequently, experimental curves were plotted and fitted with the numerical simulation results. Figure 2 presents the comparative error values between numerical simulation results and pullout test outcomes under different normal pressures for both non-wrapped and wrapped scenarios. It is evident from the error analysis that, across the four normal pressure levels, the disparities between the numerical simulations and the pullout test results are minimal. This underscores the reliability of our numerical model, affirming its capability to effectively replicate the interaction between the reinforcement material and the soil. With this foundation, further analysis of various parameters can be conducted.

Normal stress, specimen dimensions, flat placement length, wrapping height, wrapping length, and the number of test groups.

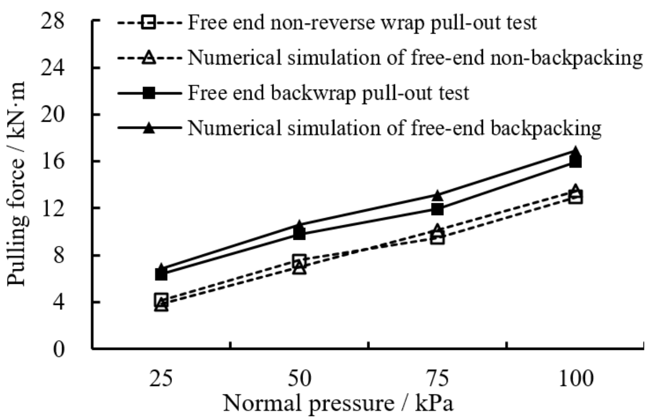


Fig. 2. Comparison of peak pullout force in pullout test and numerical simulation with and without back wrapping of free end of geotextiles.

3 Discussion and Analysis

3.1 Discussion on Geosynthetic Wrapping Height and Length

In accordance with the previously described methodology, we established finite element models to simulate pullout tests under varying geosynthetic wrapping heights. The geosynthetic fabric's laid length (L) was set at 100mm, normal pressure (P) at 50kPa, and the pullout displacement was defined at 10mm, with a wrapping length (d) of 50mm.

Figure 3 illustrates the variation in geosynthetic fabric pullout force as the pullout displacement increases while keeping the wrapping length constant at 50mm. The findings reveal that prior to reaching a pullout displacement of 0.5mm, the pullout force exhibits rapid growth. Between pullout displacements of approximately 0.5mm to 1mm, the rate of increase in pullout force significantly decelerates. Subsequently, the force gradually stabilizes. Geosynthetic fabric pullout without wrapping shows an almost linear force-displacement relationship, while geosynthetic fabric pullout with free-end wrapping exhibits a slow upward trajectory.

When employing the wrapping technique with varying heights (h) of 5mm, 10mm, 30mm, 50mm, 70mm, 100mm, and 150mm at a pullout displacement of 10mm, the corresponding pullout forces are 7.705kN/m, 8.287kN/m, 8.083kN/m, 8.101kN/m, 8.088kN/m, 8.109kN/m, and 8.159kN/m, respectively. Notably, at a wrapping height of 10mm, the increase in geosynthetic fabric pullout force is most pronounced, approximately 20.12%. In contrast, a wrapping height of 5mm results in the smallest increase in pullout force when employing the wrapping method, around 11.68%. For other wrapping heights (30mm, 50mm, 70mm, 100mm, and 150mm), the range of force increase compared to unwrapped conditions falls within the range of 17.33% to 18.26%.

A comparative analysis suggests that employing free-end wrapping for geosynthetic fabric requires greater resistance to be pulled out, demonstrating enhanced anchoring strength. Consequently, the fabric provides a higher pullout force. Free-end wrapping plays a significant role in increasing the pullout force. Moreover, the graph indicates that increasing the wrapping height does not necessarily translate into greater pullout force. With a laid length of 100mm and normal pressure set at 50kPa, a wrapping height of approximately 10mm delivers the maximum pullout force.

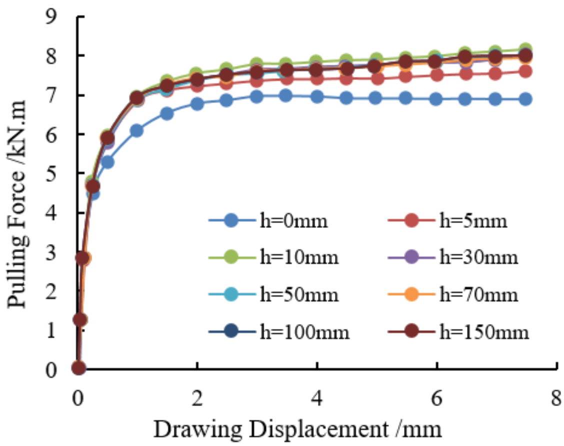


Fig. 3. Graph Depicting the Relationship Between Pullout Force and Displacement for Various Unwrapping Heights.

To investigate the influence of wrapping length on the pullout force of geosynthetic fabric, we established a numerical model based on the conclusions drawn from the previous simulations. This model simulated pullout tests with a constant free-end wrapping height (*h*=10mm) and varying wrapping lengths.

In Figure 4, we observe the variation in geosynthetic fabric pullout force as the pullout displacement increases, while maintaining a constant wrapping height. The relationship between pullout force and pullout displacement follows a trend similar to that in Figure 3. Initially, there is a rapid increase in pullout force within the range of 0mm to 0.5mm of pullout displacement. The rate of increase in pullout force markedly decelerates between 0.5mm and 1mm of pullout displacement, and beyond that point (1mm to 10mm), the pullout force gradually stabilizes.

For the free-end unwrapped condition, the pullout force peaks at approximately 3.5mm of pullout displacement (6.96kN/m). Subsequently, the pullout force remains relatively constant and follows an approximately linear trend.

At a pullout displacement of 10mm, the pullout forces corresponding to wrapping lengths of 5mm, 10mm, 30mm, 50mm, 70mm, 100mm, and 150mm are 8.132kN/m, 8.220kN/m, 8.277kN/m, 8.287kN/m, 8.379kN/m, 8.271kN/m, and 8.277kN/m, respectively. Notably, the maximum pullout force occurs at a wrapping length of 70mm, resulting in an increase of approximately 21.45% compared to the free-end unwrapped condition. Conversely, at a wrapping length of 5mm, the geosynthetic fabric pullout force is at its minimum, exhibiting an increase of approximately 17.87% compared to the unwrapped condition. The range of increase in pullout force for other wrapping lengths falls within the range of 19.18% to 20.12%. It is evident that the pullout force is only marginally affected by the wrapping length, and increasing the wrapping length does not significantly enhance the pullout force.

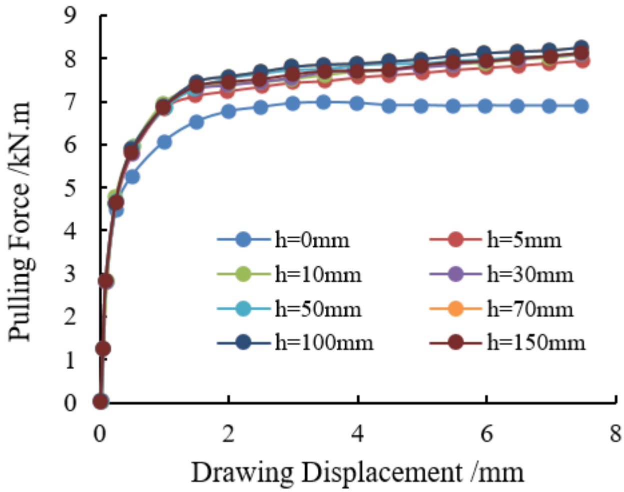


Fig. 4. Plot of pullout force versus pullout displacement for different backpacking lengths.

3.2 Discussion on Geosynthetic Fabric Laying Length

Figure 5 illustrates the relationship between the increased ratio of pullout force with wrapped geosynthetic materials to pullout force without wrapping and the pullout displacement for various geosynthetic fabric laying lengths. As shown in Figure 4, the increased ratio of pullout force due to wrapping grows with the increasing pullout displacement. At a pullout displacement of 50mm, the increase ratios for geosynthetic fabric laying lengths of 50mm, 100mm, 150mm, and 200mm compared to the unwrapped condition are 157.28%, 78.10%, 45.66%, and 20.11%, respectively. Notably, when the geosynthetic fabric laying length is 50mm, the increased ratio of pullout force due to wrapping experiences the fastest growth, exhibiting an approximately linear trend concerning pullout displacement. Conversely, with a geosynthetic fabric laying length of 200mm, the growth is slower.

It is evident that the longer the geosynthetic fabric laying length, the more gradual the increase in the ratio of pullout force due to free-end wrapping. This phenomenon is attributed to the fact that as the pullout displacement increases, longer geosynthetic fabric laying lengths result in stronger free-end anchoring forces. Consequently, the axial pullout force in the geosynthetic material needs to travel a greater distance from the pullout end to the free end before inducing sliding and eventual pullout. Therefore, the enhancement of pullout force by adopting the wrapping method at the free end is more pronounced when the geosynthetic fabric laying length is relatively short.

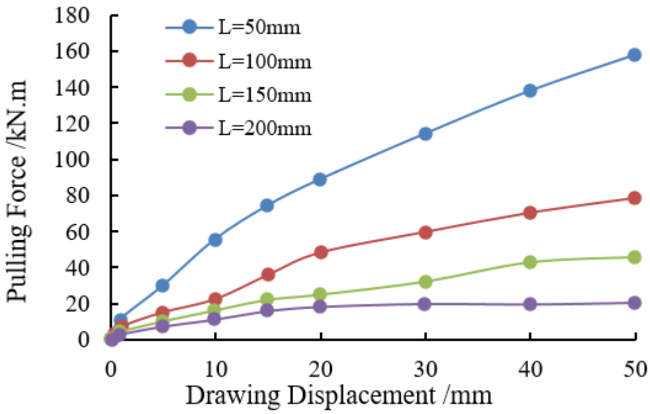


Fig. 5. The curve of pullout force increase ratio versus pullout displacement for different lay lengths of backpacking compared to no backpacking.

4 Conclusion

This paper primarily conducts a numerical simulation study of geosynthetic material pullout tests using the PLAXIS 2D software. The following conclusions are drawn:

- When geosynthetic materials are laid with free-end wrapping, they require greater resistance to be pulled out compared to the non-wrapped condition. The use of free-end wrapping significantly enhances the pullout force of the geosynthetic material.
- Numerical simulation research on the impact of different free-end wrapping heights and lengths on the pullout force of the geosynthetic material concludes that the influence of free-end wrapping length and height on pullout force is relatively minor.
- The study's numerical simulations demonstrate that as the geosynthetic fabric laying length increases, a greater pullout force is required to pull out the geosynthetic material. Consequently, in cases of shorter geosynthetic fabric laying lengths, adopting the free-end wrapping method results in a more pronounced enhancement of pullout force.

Acknowledgments

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