



Effect of Vertical Load on Shear Characteristics of Micro-Piles in Landslide

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Abstract

In recent years, micro-pile has been widely applied to landslide treatment engineering due to its advantages in application and construction. Its engineering effect is quite evident. At present, some researchers focus on studying the effects and failure mode of micro-pile in landslide reinforcement. However, only few of them discussed how the pile works with shearing force and vertical load. By numerical simulations, a part of which were compared with the results from large-scale physical model tests, effects of vertical load on shear characteristics of micro-piles in landslide were analyzed. Each row of piles simultaneously sheared with vertical loads, which played an active role in increasing anti-sliding force. According to the analysis, the four rows of piles, installed close to trailing edge, were mainly affected by compression, comparing to the rows installed in front, which are affected with tension.

Keywords

Micro-pile • Vertical load • Physical model test • Numerical simulation • Shearing force

Background

Installation of micro-piles to improve stability of slopes has been highly effective in recent decades, and it is widely used in landslide remediation projects because of its advantages, such as requiring small equipment, adaptability to various soils, low noise, minimal disturbance on slope during construction, flexible forms to pile location, etc.

At present, many researches in the world have been studying the shearing characteristics of micro-piles. Thompson (2004) and Su (2010) used of the shearing box model to study the mechanism of micro-piles under lateral

load. Sun et al. (2010), Xiao (2008) and Andrew (2006) conducted model tests to investigate sliding mechanism of the micro-piles in landslide. Yan (2010) and Wang et al. (2010) also made large-scale model tests to study failure mode and sliding mechanism of the micro-piles in landslide.

These authors focused on stress situation, failure mode and the sliding mechanism of micro-piles, rather than the relationship between shear properties and the vertical load. Impact of vertical load on shear properties for micro-pile was discussed based on results from numerical simulations, and parts of the results were compared with results obtained from large-scale physical model tests.

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Numerical Simulation Model

Numerical simulation model test adopted geometric similarity ratio $C_g = 3$, elastic modulus ratio $C_E = 1$ as basic similarity ratio, and listed similar criterion equation as of π type according to the similarity principle. Accordingly, the physical quantities were calculated as follows: $C_q = 3$,

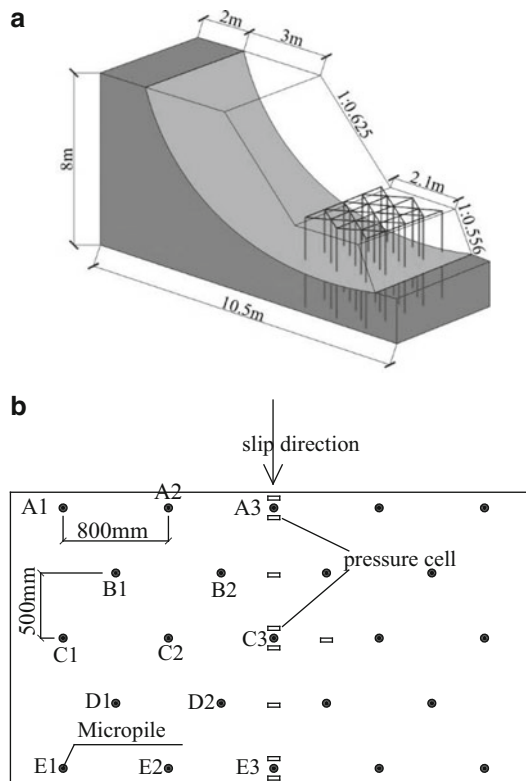


Fig. 1 Model for test and numerical simulation and the serial number of piles. (a) Model size, (b) Serial number of piles

$C_p = 9, C_\sigma = 1, C_\varepsilon = 1, C_{Ac} = 9, C_{As} = 9, C_{\sigma s} = 1$. Here, the subscripts q is the linear load, p is the force the piles are subjected to, σ is the stress, ε is the strain in the pile, Ac is the cross-sectional area, As is the reinforcement cross-sectional area of the piles, and σs is stress in the soil (Yan 2010).

Numerical Model Design

Numerical model was assumed to be homogeneous body with weak surface between the slide and the slide bed as slip surface.

The piles were 4 m in length and 60 mm in diameter, corresponding to prototype pile with length of 12 m and diameter of 180 mm, respectively.

The piles were circular in shape and laid as quincunx by 5, 4, 5, 4, 5 (sign row A, B, C, D, E) pattern along the pile load transfer direction with coupling rigid beam connection on the top. The strength of pile was at the grade of C25. Multi-stage loading approach was utilized with the corresponding pressure value of 8, 16, 24, 32, 40, and 48 kPa. The size of the test model and the chosen monitoring pile are shown in Fig. 1. Likewise, the model for numerical simulation is shown in Fig. 2. Monitoring nodes are shown in Fig. 3. Physical and mechanical parameters are: loess

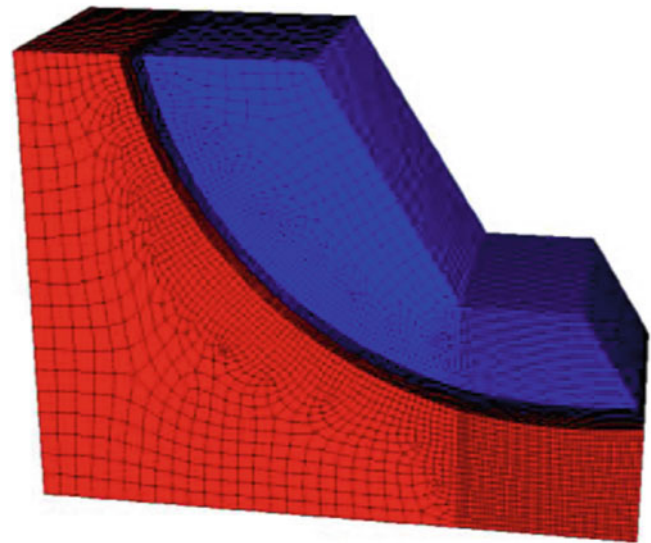


Fig. 2 Model for numerical simulation

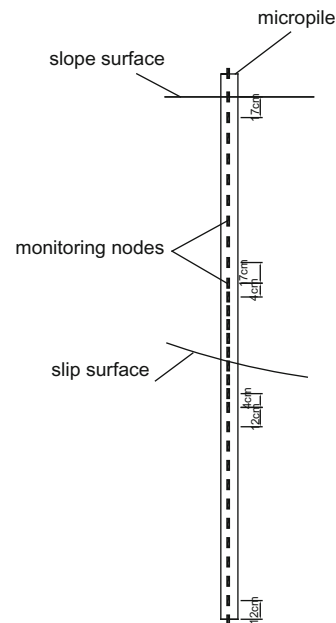


Fig. 3 Schematic diagram of monitoring nodes

friction angle $\phi = 11.7^\circ$, cohesion $c = 24.6$ kPa, density $d = 1,400$ kg/m³; sliding surface friction angle $\phi = 15^\circ$, cohesion $c = 3.5$ kPa.

Results and Analyses

Shearing forces at each stage of pile A1 from numerical simulation are shown in Fig. 4. Comparisons of this result with that of the monitoring piles with vertical load are presented in Figs. 5, 6, 7, and 8.

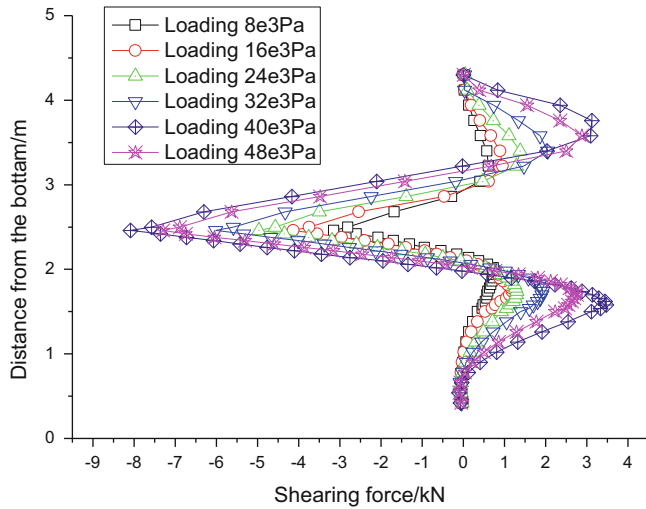


Fig. 4 Shearing force at each stage

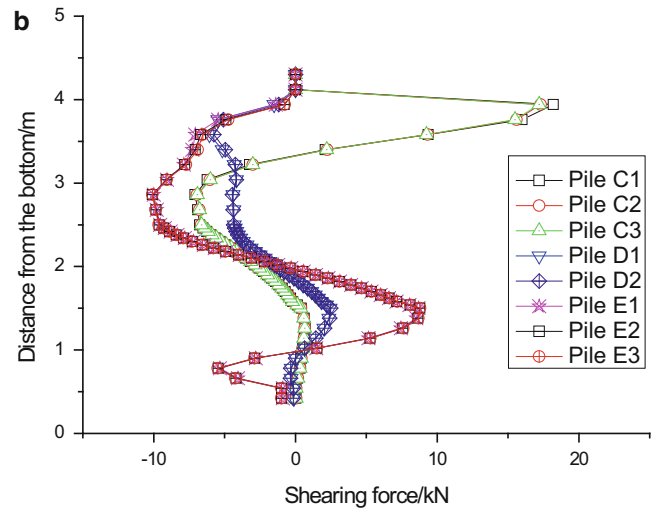
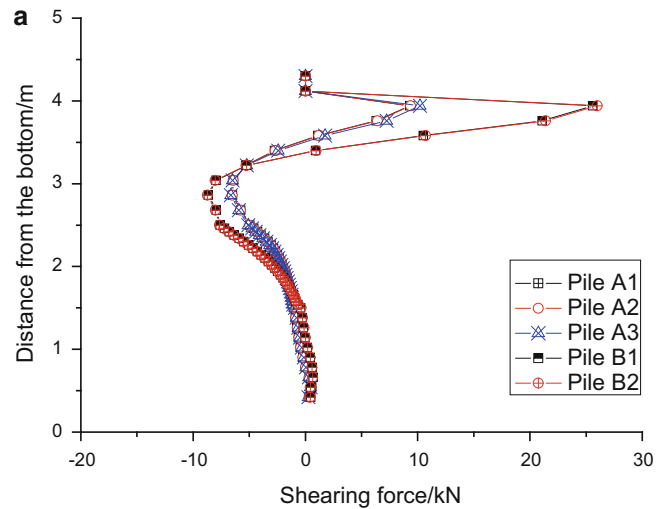


Fig. 6 Shearing force distributed in piles with 100 Pa vertical load. (a) Shearing force distributed in rows A and B. (b) Shearing force distributed in rows C–E

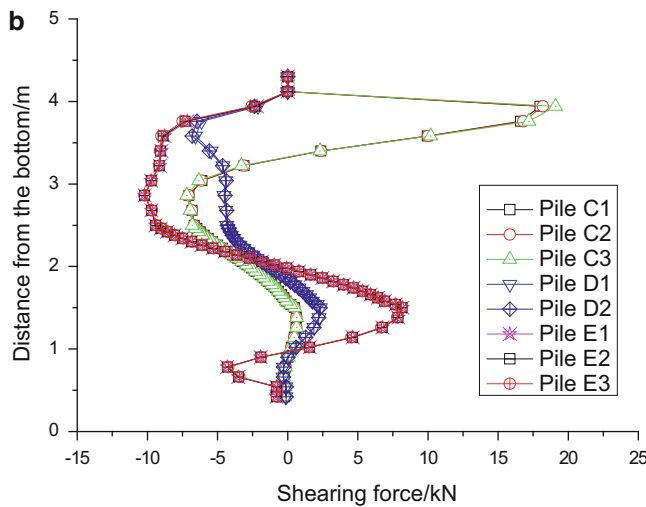
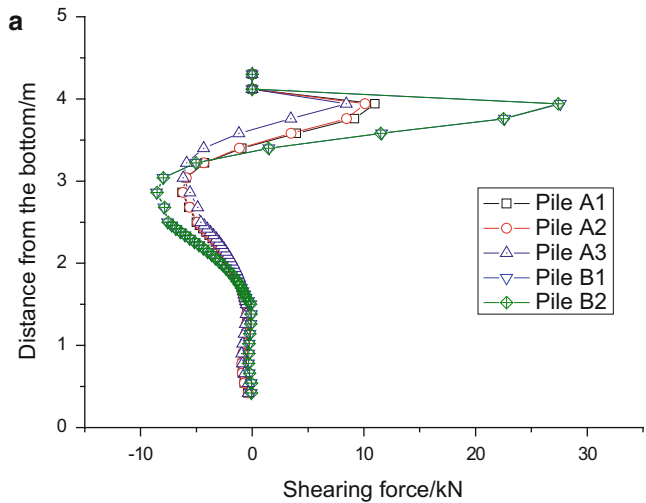


Fig. 5 Shearing force distributed in piles with 50 Pa vertical load. (a) Shearing force distributed in rows A and B. (b) Shearing force distributed in rows C–E

As can be observed in Fig. 4, with no vertical loads on top of piles, we can see that the form of shearing force distributed along the pile is like a shape of “M”, turned perpendicular on left; each shear curve has three peaks, and the peak near the slip surface is in the same direction as in the sliding mass, comparing with the ones close to the top and bottom of the micro-pile in the opposite direction. Shearing curves on and under the slip surface are approximately symmetrical about the surface. The maximum value of shearing force is located near the sliding surface, which moves closer to the top of pile with an increase in loading on the slope surface, reaching close to 2–3 cm. Likewise, the two peaks close to top and bottom move slightly to the tips of the micro-pile with the maximum distance of 50 cm. Shearing force of each row of piles decreases in turn along the direction of load transfer.

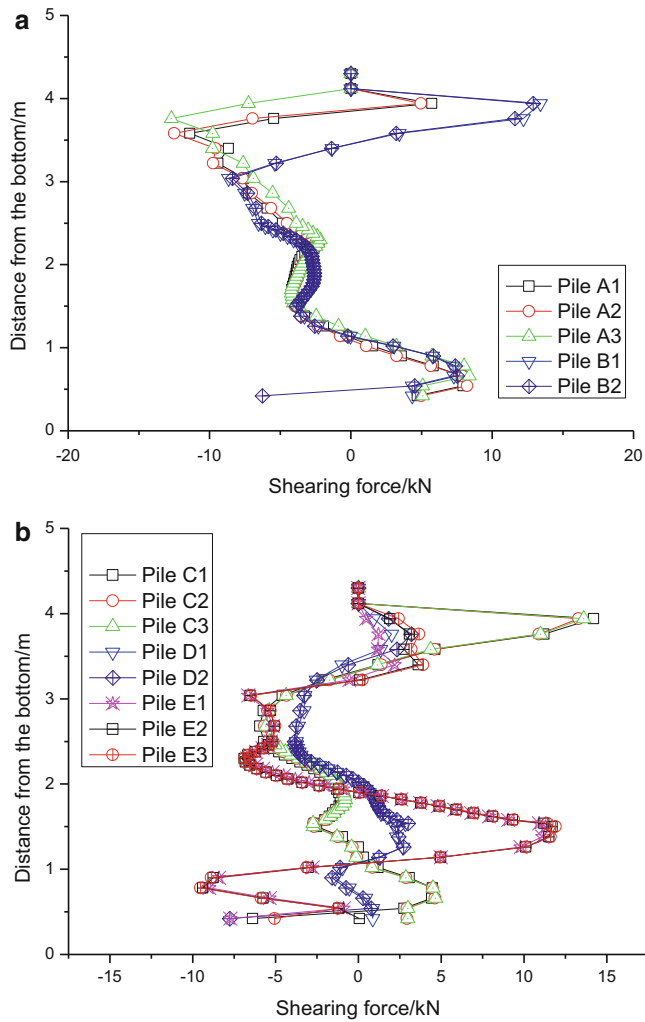


Fig. 7 Shearing force distributed in piles with 400 Pa vertical load. (a) Shearing force distributed in rows A and B. (b) Shearing force distributed in rows C–E

As can be observed in Figs. 5, 6, 7, and 8, vertical load plays a significant role on the shear force in the piles; and each row of piles charges the shearing force simultaneously.

Existing data showed that the landslide thrust distributed triangularly along the pile with the maximum near the slip surface, which means that the landslide thrust of the third monitoring node is close to 0. Results from numerical simulation show that its value is larger than 0, which relates to the small lateral confinement because of its position of close to the slope surface. Let's take Fig. 9 as an example; nodes near the slope surface firstly break because of excessive deformation when loading to 1,200 Pa.

Shearing force in each pile of row A is less than that of row B, which may be related to the number of piles between row A and B. The “zero” points near the slip surface usually exists when vertical loads are added on micro-piles, and their position usually do not change concomitantly with the

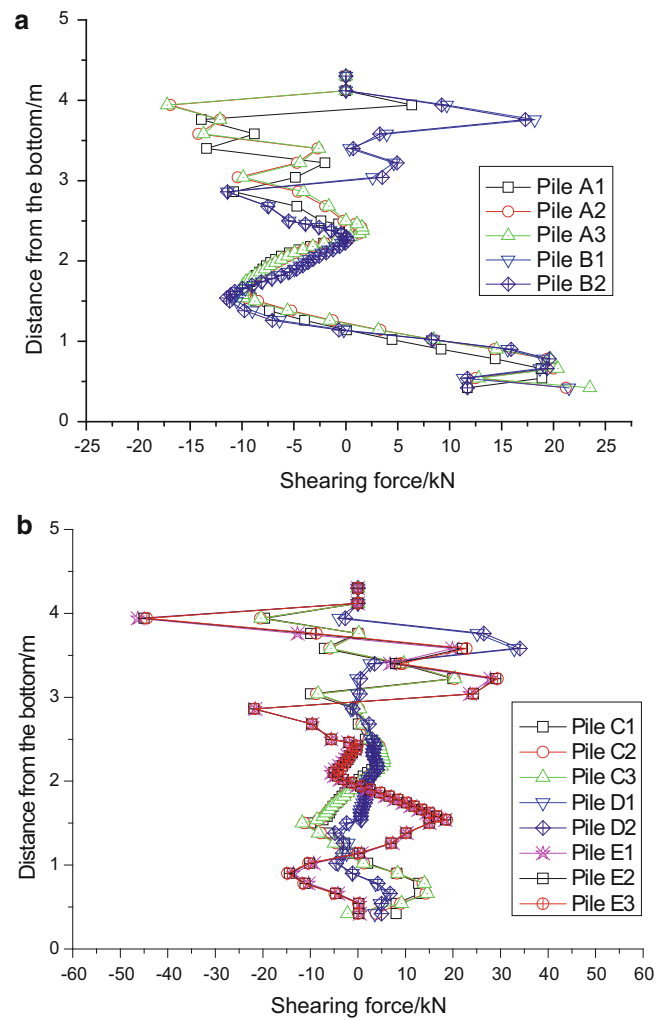
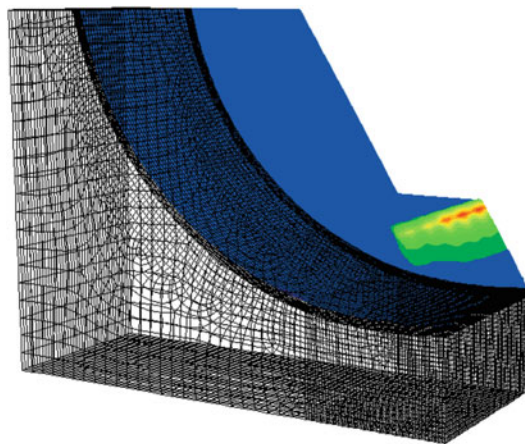


Fig. 8 Shearing force distributed in piles with 800 Pa vertical load. (a) Shearing force distributed in rows A and B. (b) Shearing force distributed in row C–E

increase of the vertical load. When the vertical loads are small (such as 50 Pa, 100 Pa), the maximum values of shearing force in the pile are less than 10kN. Moreover, each pile has different values. At the same time, there are no shearing forces at the bottom of the piles. So, we can conclude that smaller vertical load has little effect on enhancing the shear force capability of the pile. However, for the higher vertical loads (such as 400, 800 Pa), a great variations in the shearing forces appear at the bottom of each pile. Although the values are opposite, they also have a uniform distribution around the zero value, which are helpful to strengthen the shearing capacity of micro-piles.

Existing research data (Zhou et al. 2009) shows that the piles can take tensile loads of the landslide thrust when the piles reach the yield condition.

A very interesting phenomenon is that the maximum value of shearing force and the maximum range of variation



Contour of X-Displacement

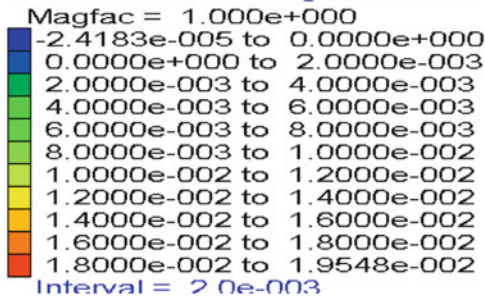


Fig. 9 Contour of x-displacement for landslide

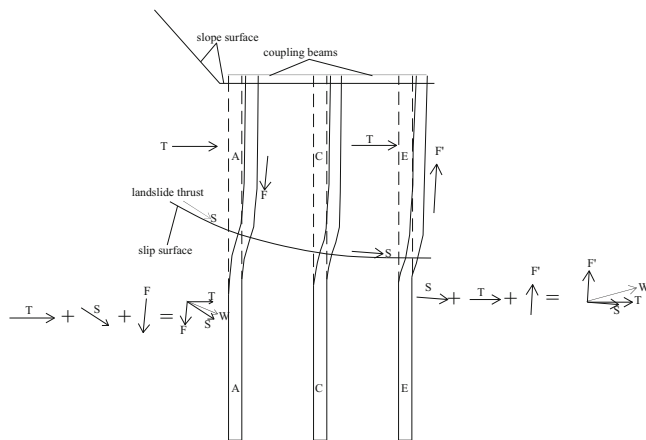


Fig. 10 Schematic diagram for force distributed on piles

were observed in row E, among the rows C, D, and E. Analyzing its force process (Fig. 10), we can see that rows A and E mainly undertake extrusion (T) from soil between piles, landslide thrust (S) at the slip surface, tensile force

after broken (F or F'), the difference in value of which and direction of resultant leads to different shearing force. According to the analysis presented above, row A is mainly affected by compression, compared to row E, which is affected with tension.

Discussion

The shearing force along the pile mentioned in the text are instantaneous among of the process of iterative calculation, which means that it can not represent the whole process of loading, and the value is only with regular statistical significance.

Conclusions and Recommendations

Each row of piles shears simultaneously with the vertical loads on the top of piles. When the vertical load increases to a certain value, shearing forces appear at the bottom of the pile, and at the same time, longer piles are needed in the anchored segment. Vertical loads play an active role in increasing anti-sliding force for micro-piles. The “zero” points near the slip surface usually exist when adding vertical loads on micro-piles. The four rows close to trailing edge are mainly affected by compression, compared to the row in front, which is affected with tension.

References

- Andrew ZB (2006) Load transfer in micropiles for slope stabilization from tests of large-scale physical models. MS thesis, University of Missouri, Columbia, Columbia, MO, p 69
- Sun SW, Zhu BZ, Ma HM (2010) Model experimental research on anti-sliding characteristics of micropiles with cap beam. *Chin J Rock Mech Eng* 29(Supp. 1):30
- Su YY (2010) Model tests on grouted micro-steel-tube pile in earth slope. MS thesis, Ocean University of China, Qing Dao, China, p 16
- Thompson MJ (2004) Experimental load transfer of piles subject to lateral soil movement. In: *Transportation scholars conference*, Ames, IA, pp 18
- Wang SF, Yin YP, Men YM (2010) In-situ test and numerical analysis of skid resistance for micropile to loess landslide. *Hydrogeol Eng Geol* 37(6):22–26
- Xiao WM (2008) Study on anti-sliding mechanism of micro-pile structure. MS thesis, Southwest Jiaotong University, ChengDu, China, p 16
- Yan JK (2010) Model test study on micropiles in landslide reinforcement. DR thesis, Chang'an University, Xi'an, China, pp 71–98
- Zhou DP, Wang HL, Sun SW (2009) Micro-pile composite structure and its design theory. *Chin J Rock Mech Eng* 28(7):1354–1356