Abstract. By using the finite element numerical simulation method, the simplified Bishop method and strength reduction method are used to analyze the stability of a high slope which is protected and treated by anti slide pile combined with prestressed anchor cable grading scheme in Guangdong Province, and the similarities and differences between rectangular pile and plum shaped circular pile in slope treatment effect are compared. Through calculation and analysis of field measured data, it is proved that the circular anti slide pile with plum shaped layout has similar effect with the traditional rectangular anti slide pile, and has the advantages of high degree of mechanization construction and low construction safety risk, so it can be used as the alternative scheme of rectangular pile.

1. Introduction
The anti slide effect of anti slide pile is mainly to balance the landslide thrust by using the anchoring effect of stable stratum and passive resistance. It has the advantages of strong anti sliding ability, wide application conditions and simple construction, so it is widely used in slope engineering of expressway, railway and port. According to the construction method, anti slide piles can be divided into driven piles, bored piles and dug piles; according to the materials, they can be divided into wood piles, steel piles and reinforced concrete piles; according to the cross-section shape of piles, they can be divided into round piles, tubular piles and rectangular piles, etc. The traditional anti slide pile generally adopts square section, but the rectangular pile needs manual excavation, which has low mechanization rate and high safety risk. It is generally impossible to guarantee dry operation construction in karst area, water gushing geological fault zone and southern area with rich groundwater. Therefore, most construction departments explicitly prohibit or restrict the use of manual bored pile.

Taking a highway high slope in Guangdong Province as an example, this paper studies the feasibility of using plum shaped double row round piles instead of traditional rectangular anti slide piles, and proves its feasibility by comparing the field measured data.

2. Project overview
The K60-K66 line of an expressway construction section in Guangdong Province is parallel along the long slope, with a natural slope rate of 1:1.5-1:2.5, which is relatively steep and has complex geological conditions. According to the preliminary and detailed exploration results, the area is mainly distributed with quaternary silty clay, Upper Devonian strongly weathered sandstone, fully weathered sandstone and moderately weathered limestone. The selected test section K 64+360-K64+480 high
slope section is located on the right side of the highway, with a slope length of 120m and a maximum slope height of 34.8m. The main rock and soil layers of the slope are silty clay, strongly weathered argillaceous sandstone and moderately weathered argillaceous sandstone.

In order to ensure the slope stability of the road section, the original design adopted the following treatment scheme: 1:1.25 slope ratio is adopted for slope cutting by steps, at the same time, tension type anchor cable and lattice beam are set on the second and third slope surface, anti slide pile is set in the lower step, the anti slide pile used for retaining is rectangular section, the cross section size is 2.0m \(	imes\) 3.0m, the pile spacing is 5m, the pile length is 24m, and the rectangular anti slide pile is manually excavated Construction is carried out.

Considering that the rectangular anti slide pile construction needs manual excavation, and according to the exposure of geotechnical engineering geological drilling in this section, the geological conditions of the slope of this section are poor, some anti slide piles are located in limestone area, and the project site is rainy all the year round, typhoon and rainstorm in summer, so the safety risk of manual excavation construction is high and the mechanization rate is low. As the construction period is tight, circular anti slide pile is considered The alternative scheme can improve the mechanization rate and reduce the construction risk.

3. Stability analysis of original slope
Taking the typical section K64+400 in K64+360-K64+480 mileage section as a representative, the stability analysis of the slope excavation scheme (close to the natural state) under the unsupported state of the section is carried out. The finite element strength reduction method (MIDAS GTS) is adopted for the analysis and calculation NX and PLAXIS software) and simplified Bishop method (GEO-SLOPE) are used to compare the calculation results with the original design results. The calculation is divided into normal working condition and abnormal working condition. Under normal conditions, the cohesion of strongly weathered gravelly sandstone is 24 kPa, and the internal friction angle is 23 °. The cohesion is 22 kPa and the internal friction angle is 19 ° under abnormal working conditions. The comparison results of two-dimensional analysis are summarized in Table 1.

Table 1. Comparison of two-dimensional calculation results of slope stability without support

| Method          | Software       | Safety factor of slope | Normal condition | Abnormal condition |
|-----------------|----------------|------------------------|------------------|-------------------|
| Strength reduction | MIDAS GTS NX   | 1.016                  | 0.855            |
|                 | PLAXIS         | 1.032                  | 0.870            |
| Simplified Bishop | LI ZHENG      | 1.084                  | 0.887            |
|                 | GEO-SLOPE      | 1.069                  | 0.899            |
Through the above comparison results, it is found that the slope stability coefficients obtained by different software and different analysis methods are similar, which shows that the results of slope stability calculation by using Midas GTS NX software are reliable. Therefore, Midas finite element strength reduction method is adopted for the subsequent slope stability simulation calculation.

4. Analysis of circular anti slide pile with plum shaped arrangement

4.1. Numerical analysis and calculation

The three-dimensional finite element strength reduction method is used to compare the design scheme before and after the change. The summary information before and after the change of typical section slope treatment scheme is shown in Table 2.

| Slope height | Soil | Original design | Design after change |
|--------------|------|-----------------|---------------------|
| 34.8m | Silty clay | Rectangular anti slide pile 2.0×3.0m | Plum shaped layout Row spacing of 3.5m |
| | Moderately weathered argillaceous limestone | Pile length 24m | Pile length 24.0m |
| | Argillaceous limestone | Spacing 5m | Pile spacing of 5m |

The original design scheme and the modified scheme are calculated respectively, and the soil mechanical parameters are consistent with the original design scheme, as shown in Table 3. The calculation is divided into two conditions, normal condition and abnormal condition (considering the influence of rainfall). The slope stability under these two conditions is calculated respectively.

| Soil | Condition | γ/kPa | c/kPa | φ/(°) |
|------|-----------|-------|-------|-------|
| Silty clay | Normal condition | 19.5 | 22 | 20 |
| | Abnormal condition | 19.0 | 18 | 15 |
| Moderately weathered argillaceous limestone | Normal condition | 21.0 | 28 | 21 |
| | Abnormal condition | 20.0 | 25 | 18 |
| Argillaceous limestone | Normal condition | 22.5 | 25 | 22 |
| | Abnormal condition | 22.0 | 22 | 19 |
| Pile | | 25.0 | / | / |
| Prestressed anchor cable | | 78.0 | / | / |
| Reinforced concrete coupling beam | | 25.0 | / | / |

Figure 3. Model of rectangular anti slide pile

Figure 4. Model of round pile design scheme
The strength reduction method is used to calculate the stability of the original design scheme and the changed scheme. The results are shown in Table 4.

Table 4. Numerical calculation results

| Section form of anti slide pile | Safety factor of slope | Normal condition | Abnormal condition |
|--------------------------------|------------------------|------------------|-------------------|
| Rectangular pile               | 1.25                   | 1.17             |                   |
| Plum shaped circular pile      | 1.23                   | 1.15             |                   |

From the above calculation results, it can be seen that the safety factor of double row round pile with plum shaped layout is close to that of rectangular pile under normal and abnormal conditions. Whether rectangular anti slide pile or round pile is adopted, there are potential sliding surfaces at the interface between silty clay and strongly weathered argillaceous limestone, and there is a plastic zone at the first grade slope, especially at the toe of the slope.

According to the calculation results, the bending moment of the front row pile is smaller than that of the back row pile, and the maximum bending moment of the back row pile is close to the top of the
pile. Due to the passive soil in front of the pile and the reinforcement effect of the upper slope on the soil, the reverse bending points appear in both circular pile and rectangular pile. Due to the restraint of the coupling beam at the top of the pile, the maximum bending moment of the circular pile is located in the upper part of the pile, the bending point is located in the middle of the pile, the maximum bending moment of the rectangular pile is close to the bottom, and the bending point is close to the top of the pile.

4.2. Field data analysis

In order to obtain the actual stress of anti slide pile, stress meters are embedded in rectangular and circular anti slide piles respectively to monitor the pile stress after excavation of soil in front of anti slide pile. After the soil in front of the pile is excavated and stabilized, the bending moment of the pile body converted according to the stress is shown in the figure12.

![Figure 12. Measured value of pile bending moment](image)

The actual stress of rectangular pile is about 25% larger than that of numerical calculation, while that of circular anti slide pile is about 10% less than that of numerical calculation. This is due to the fact that the plum shaped piles are formed as a whole by coupling beams in the longitudinal direction of the whole slope, which is stronger than that of the numerical analysis with a single element for calculation. The plum shaped circular pile makes up for the problem that the soil arching effect of the circular pile is not obvious, which makes the pile and soil form a whole force, and also reduces the internal force of the pile body.

From the field construction situation, numerical calculation and stress test comprehensive analysis, it can be seen that the plum shaped circular anti slide pile can be used as the alternative scheme of rectangular pile, and the construction speed is fast and the safety is high.

5. Conclusion

(1) Anti slide pile retaining is a common engineering measure in slope treatment, but there are many difficulties in quantitative evaluation of its treatment effect. The engineering examples in this paper show that it is feasible to analyze the effect of slope treatment by using two-dimensional or three-dimensional finite element strength reduction method.

(2) Under normal and abnormal working conditions, the safety factor of slope stability of plum shaped double row circular pile scheme is close to that of corresponding rectangular pile, and the pile body and soil form are under joint force, and the anti sliding effect is good, so it can be used as an alternative to the original design scheme.

(3) The field practice shows that compared with rectangular section anti slide pile, circular anti slide pile has a higher degree of mechanization construction, which can greatly improve the construction efficiency and reduce the construction safety risk.
References

[1] TIAN Xiao-bo. (2012) Optimization design and application of prestressed anchor friction piles. Journal of Railway Science and Engineering, 04:89-93.

[2] ZHOU De-pei, XIAO Shi-guo, XIA Xiong. (2004) Discussion on rational spacing between adjacent anti-slide piles in some cutting slope projects. Chinese Journal of Geotechnical Engineering, 26:132-135.

[3] LEI Guoping, TANG Huiming. (2013) Study of improved design method of anti-slide pile socketed segment. Chinese Journal of Rock Mechanics and Engineering, 32:605-614.

[4] FENG Yu-guo, WANG Wei-ming. (2009) Robust optimization design of anti-slide piles with prestressed anchor cables. Chinese Journal of Geotechnical Engineering, 31:515-520.

[5] Zhang Xiao-xi, He Siming. (2012) Optimum design of deeply embedded anti-slide pile. CHINA Civil Engineering Journal, 45:143-149.