Stability Analysis of Embankment with Squeezing Thick Silt by Blasting

Xiaolian Xu¹ and Xueyong Xu²,*
¹Ezhou Polytechnic, Hubei Ezhou 436000, China
²Power China Huadong Engineering Corporation Limited, Hangzhou 310014, China
*Corresponding author e-mail: xxy-cas@126.com

Abstract. Blasting squeezing silt technology plays an important role in the marine reclamation and tidal power station seawall project construction. The thickness of soft clay gradually deepening with the ocean engineering progresses to offshore and underwater shoals. The suspended seawall structure appears in over 12m deep soft clay. Carrying out stability analysis of these seawall structures has important significance and application value. In this paper, aim at a revetment engineering stability analysis, the traditional stability analysis method and numerical simulation method were applied. Furthermore, applicability and rationality were analyzed for these methods. Studies have shown that, the safety coefficient obtained by the Swedish strip method is low, and it cannot even meet the requirements of the overall anti sliding stability in the construction period and the earthquake condition. The assumptions of Bishop, Janbu and FLAC based finite element method were closer to the actual engineering conditions. The calculated results were reliable and could be applied to the calculation of the suspended seawall.

1. Introduction
The technology of blasting and silting and building embankment has the advantages of simple construction process, fast speed and good treatment effect of soft foundation. It has been widely used in the construction of embankments and cofferdams in marine water conservancy and tidal power stations, and it is widely used in [1, 2]. With the continuous development and advancement of these marine projects, the thickness of the silt (soft base) needs to be gradually deepened (from the conventional 12m to 30-40m), and the corresponding dike cross-section form has developed from "bottom down type" to "suspended type" [3, 4]. The "bottom down type" is the height of the bottom of the rock fill after blasting, and it falls completely to the high strength bearing layer, such as sandy silt, gravel or rock [5]. Usually, the sludge with small thickness (3~12m) can be used as the "bottom down type". For deep silt (12~40m), it is difficult to replace all of them. If all of them are replaced, the construction is very difficult and the cost is too high [6]. Therefore, "suspended type" section structure is often adopted in deep silt.

The engineering practice shows that the bottom height of the "bottom down type" dam falls on the bearing layer with higher strength, and the settlement after operation is small, generally only a few centimeters [7]. The bottom elevation of the "suspended type" dyke can not fall above the high strength bearing stratum, but the whole "suspension" in the soft soil layers such as silt, clay and silt,
etc. Soft soil foundation will continue to take consolidation settlement under long-term external load, which will cause potential damage to the overall stability of dam structure [8, 9]. At present, there are more and more "suspended type" dams in coastal deep silt geological area, and the calculation and analysis of their stability is very rare. Therefore, the stability analysis and research of the "suspended type" dyke structure formed by blasting compaction is of great application value.

Taking the revetment engineering of the Huizhou port flourishing oil depot (50 thousand ton grade Petrochemical dock) as an example, the stability calculation and analysis of the embankment and dam formed by the blasting and silting are analyzed by the limit equilibrium analysis method and the FLAC numerical calculation method, and the applicability and rationality of these methods are analyzed, which are "suspension type". It provides technical support for dam design and provides reference for similar projects.

2. The limit equilibrium analysis
Sweden's slice method, Bishop method and Janbu method are widely used in the stability calculation and analysis of water conservancy dam design. These three methods are used in this experiment. Five kinds of calculation conditions are selected to analyze the stability of the limit equilibrium for the embankment of Xingsheng oil depot revetment project in Huizhou port. According to the specific calculation conditions, the safety factor of anti slide stability of bank revetment slope (back sea slope or coastal slope) is calculated respectively. The stability analysis software of the rock slope soil slope is used to calculate the stability of anti sliding, and the results of the safety coefficient of Swedish strip method, Bishop method and Janbu method are obtained respectively. (Table 1)

According to the calculation results, the safety factor calculated by Swedish slice method is low. Under construction and earthquake conditions, it is not even able to meet the requirements of stability against sliding. Engineering application shows that the traditional Swedish slice method can only partially satisfy the torque balance, and does not consider the interaction force between soil strips. Therefore, the calculation results deviate from the actual ones. The Bishop method and Janbu method can satisfy the torque balance and consider the interaction force between soil strips. The Bishop method assumes the direction of the joint force between the stripe forces. The Janbu method assumes that the inter stripe force acts on the 1/3 above the soil bar. These assumptions are closer to the actual engineering conditions. Therefore, in view of the stability analysis of the slope engineering of blasting and silting dam, the calculation results of Bishop method and Janbu method are more reliable.

| working condition          | side slope | Swedish slice method | Bishop method | Janbu method |
|---------------------------|-----------|----------------------|---------------|--------------|
| Design high tide (water)  | Back slope| 1.28                 | 1.53          | 1.65         |
| Design low tide (water)   | Coastal slope | 1.29               | 1.55          | 1.63         |
| Water level landing       | Coastal slope | 1.22               | 1.49          | 1.62         |
| construction period       | Back slope | 1.14                | 1.47          | 1.58         |
| Earthquake                | Coastal slope | 1.13               | 1.45          | 1.58         |

3. FLAC finite element numerical analysis
3.1. Calculation model and parameter
The FLAC numerical model is divided into two parts of the dam and the stratum. The formation structure is set according to the distribution of the rock and soil layer on the site of the revetment project, which are as follows: silt, silt clay, viscous soil gravel sand, residual clay and strong
weathered tuffaceous sandstone. The length of element in longitudinal direction is treated by plane strain. The Mohr Coulomb plasticity model is used for dam and stratum material.

The blasting compaction is to destroy the structural strength and bearing capacity of the mud by blasting dynamic action. During the process of blasting compaction, the impact and vibration of soft soil on the bottom and surrounding of the dam are disturbed. The analysis and prediction of embankment settlement need to consider the range of shock and vibration disturbances, and then reduce the strength parameters of the soil layer in accordance with the different dynamic disturbance regions, and then carry out numerical calculation.

The range of calculation: Extending the 85m from the center line of the dike to the left and right. The bottom of the dam is facing the actual thickness of the stratum. Boundary conditions: The external boundary is fixed in the horizontal direction. The vertical direction is free. The boundary of the bottom boundary is fixed in the direction of X and Y. The upper boundary is a free boundary.

The FLAC grid partition is shown in Figure 1. The calculated values of embankment and soil parameters are shown in Table 2.

![FLAC numerical model](image)

**Table 2. Material parameters.**

| parameters                  | unit      | Dam         | silt     | Silt silty clay | Cohesive soil gravel sand | Residual clay | Strongly weathered tuffaceous sandstone |
|-----------------------------|-----------|-------------|----------|-----------------|---------------------------|---------------|----------------------------------------|
| Severe γ                    | KN/m³     | 21.5        | 16.7     | 18.5            | 19.2                      | 19.5          | 22.5                                   |
| Modulus E                   | MPa       | 20000       | 2.0      | 8.5             | 12                        | 20            | 40000                                  |
| Poisson ratio ν             |           | 0.2         | 0.3      | 0.28            | 0.25                      | 0.25          | 0.2                                    |
| Cohesion C                  | kPa       | 25          | 12       | 32              | 10                        | 40            | 90                                     |
| internal friction angle φ   |           | 35          | 5.0      | 18.0            | 26.4                      | 20.4          | 45                                     |
| Permeability coefficient kᵥ | cm/s      |             |          |                 |                           |               |                                        |

| parameters                  | unit      | Dam         | silt     | Silt silty clay | Cohesive soil gravel sand | Residual clay | Strongly weathered tuffaceous sandstone |
|-----------------------------|-----------|-------------|----------|-----------------|---------------------------|---------------|----------------------------------------|
| Permeability coefficient kᵥ | cm/s      |             |          |                 |                           |               |                                        |

3.2 Calculation results and analysis

(1) Initial stress calculation

The vertical and horizontal stress nephogram of the stratum obtained by initial stress calculation. The calculated results are as follows: the maximum vertical stress value is 692kPa, and the maximum horizontal stress value is 359kPa. This is in accordance with the test value of the actual formation stress.

(2) Calculation of safety factor

According to the principle of strength reduction, the stability of embankment slope is calculated when the reduction factor is F=1.0 to 1.6. Fig. 2~4 is the shear strain slip direction and velocity vector...
graph at F=1.48, 1.50 and 1.53, respectively. Fig. 5 is Slip direction and velocity vector graph of embankment slope at F=1.53.

![Figure 2. Shear strain graph (F=1.48).](image)

![Figure 3. Shear strain graph (F=1.50).](image)

![Figure 4. Shear strain graph (F=1.53).](image)
From the calculation results of different strength reduction coefficients, it is found that the numerical calculation can converge in the range of $F=1.0$ to $1.53$ and the numerical calculation cannot converge after the strength reduction coefficient exceeds $1.53$. It shows that the large deformation of the dam slope and the large slippage of the slope can not meet the overall stability requirements. Judged by the strength reduction method, we can see that when the strength reduction factor is $1.53$, the slope reaches the critical failure state. It can be determined that the safety factor of the dam slope is $1.53$.

The advantage of the finite element analysis method is to combine the stability analysis of the dam with the stress and deformation analysis of the dam. The sliding rock mass meets the static condition naturally, without the need of introducing some artificial assumptions like the Swedish slice method. Compared with the limit equilibrium method, the finite element method can consider the nonlinear constitutive relation of rock and soil, the complex boundary condition and action, the real simulation of the stress field and displacement field inside the soil.

4. Conclusion
In this paper, combined with specific engineering examples, the stability calculation and analysis of the blasting and silting dams are calculated and analyzed by the method of limit equilibrium analysis and FLAC numerical calculation, and the applicability and rationality of these methods are analyzed, and the following conclusions are drawn.

(1) Based on the theory of limit equilibrium analysis, the safety coefficient of the slope stability of the embankment and dam in seven different working conditions is obtained by using the Swedish strip method, the Bishop method and the Janbu method respectively. The calculation results show that the safety factor of the stability of the embankment slope is greater than the allowable safety value in the engineering design code for sea embankment (GB/T 51015-2014). The slope of the embankment and dam will not produce slip damage, and the overall stability of the embankment meets the requirements of the standard.

(2) The safety factor calculated by Sweden's slice method is low. Under construction and earthquake conditions, it is not even able to meet the requirements of overall skid resistance stability. The research and engineering application show that the traditional Swedish strip method can only partially satisfy the moment balance and does not consider the force between the soil strips, so it is not suitable for the stability analysis of the blasting and silting dams.

(3) The calculation and analysis of Bishop method and Janbu method show that these two methods satisfy the torque balance and consider the interaction force between soil strips. Therefore, for the stability analysis of dam slope engineering, the calculation results of Bishop method and Janbu method are reliable.

(4) The finite element analysis method combines the stability analysis of the dam with the stress and deformation analysis of the dam body. Compared with the limit equilibrium method, the finite
element method can consider the nonlinear constitutive relation of rock and soil, the complex boundary condition and action, the real simulation of the stress field and displacement field inside the soil.

Acknowledgments
This work was financially supported by National Natural Science Fund (No. 41101519) and Zhejiang Natural Science Foundation (No. LY14D020001).

Reference
[1] ZHAO JY, WANG J, WU JP. An application of blast method to squeeze mud and replacement with controlled loading, J. Rock and Soil Mechanics, 27 (2006) 332-335.
[2] LI ZM. Theory, design and construction of soft soil foundation reinforcement. Beijing, 2006.
[3] XU XY, HU B, LI B. Centrifugal model tests on settlement characteristics of embankment using blasting compaction technology, J. Chinese Journal of Geotechnical Engineering, 37 (2015) 958-964.
[4] XU XY, WANG R, MENG QS, et al. Monitoring and controlling technology for vibration effect due to deep and thick silt by blasting compaction, J. Rock and Soil Mechanics, 29 (2008) 3256-3260.
[5] Gohl W B, Jeferies M G, Howie J A. Explosive Compaction: Design, Implementation and Effectiveness, J. Geotechnique, 50 (2000) 657-665.
[6] XU XY, WU JG, CHENG K. Treatment Technology of Thick Silt Foundation by Blasting Compaction, J. BLASTING, 28 (2011) 93-96.
[7] ZHANG JX, WANG XG, HUANG LC. Discussion about problems concerning design of compaction by blasting in the code, J. Port & Waterway Engineering, 6 (2010) 27-36.
[8] WANG WJ, ZHAO WR, GUO JG. Discussion on Hanging Explosion Technology for Base Compaction Treatment in Reclamation Engineering on Tidal Flat, J. Coastal Engineering, 29 (2010) 51-56.
[9] WANG HX. Settlement calculating method of flexible and rigid foundations considering three-dimensional deformation, J. Rock and Soil Mechanics, 34 (2013) 1874-1880.
[10] Chen XF. The computational method and research progress on settlement of deep foundation, J. China civil engineering journal, 37 (2004) 70-77.