Stability analysis of composite I-shaped masonry reinforced retaining wall

Wu Yuedong^{1,2}, Zhang Lei^{1,2}, Xu Nan^{1,2} and Lui Jian^{1,2}

¹Key Laboratory of Ministry of Education for Geomechanics and Embankment Engineering, Hohai University, Nanjing 210098, China; ²Geotechnical Research Institute, Hohai University, Nanjing 210098, China

Abstract: Based on the actual project, the influence of geogrid on the stability of the retaining wall of the single-layer masonry reinforced retaining wall is studied through field test and finite element software ABAQUS numerical simulation. The influence of geogrid on the stability of the retaining wall was determined by analyzing the changes in the pressure of the backfill, the displacement of the retaining wall and the strain of the geogrid, and changing the length and spacing of the geogrid through the controlled variable method. The results show that the geogrid can limit the horizontal displacement of the soil, balance the earth pressure, and improve the overall stability of the retaining wall. By increasing the length of the geogrid and reducing the distance of the geogrid, the design of the retaining wall is optimized, which has good economic and time benefits.

1 Introduction

In recent years, the combined I-shaped ecological masonry retaining wall has received more and more attention and praise due to its good engineering characteristics, factory prefabrication, high-efficiency construction, and ecological and environmental protection. It has been applied in traffic and water conservancy slope engineering.

In the 1960s, French engineer Vidal[1] found through model tests that the strength of the soil body was significantly improved when fiber materials were added. With the continuous promotion and use of reinforced soil technology, domestic and foreign scholars have successively carried out experimental research on reinforced soil structure [2]. University of California, Richardson [3] did a model test on the basis of theoretical analysis, but the test was limited to using a small amount of metal reinforcement; the Italian National Railway Company conducted field tests to study the stress of the reinforced earth retaining wall of different types of vehicles passing by Different responses of the field; Claus etc.[4]used indoor model tests to study the reasonable reinforcement position of the geogrid retaining wall and the change of the surface settlement under the train load.

This paper uses a combination of field test and numerical simulation to study the mechanical characteristics of the composite I-shaped masonry reinforced retaining wall. The field test is based on a certain test section of the Hang-Ping-Shen Line Channel Reconstruction Project in Zhejiang Province to conduct related research. The earth pressure of the reinforced retaining wall and the strain of the geogrid are monitored. In the numerical analysis, the related model is used to

simulate the influence of the geogrid on the mechanical performance of the retaining wall, and the influence of the geogrid parameters on the stability of the retaining wall is analyzed.

2 Field test results and analysis

2.1 Project overview

This research is based on the Zhejiang Hang-Ping-Shen Line channel reconstruction project (Wuxing Bridge-Changsheng Bridge section) for field tests. The test section is located on the right bank of the K10+050-K10+211 bid section of the Hang-Ping-Shen Line reconstruction project (Zhejiang section). The total length of the test section is 152.35 meters, of which the single-layer block section is 67.75 meters and the double-layer block section is 84.6 meters.

Fig. 1. Schematic diagram of I-shaped block structure

* Corresponding author: wu.yuedong@hhuwyd@163.com

Fig. 2. Sectional view of the bank protection design of combined I-shaped block (unit: m)

2.2 Test content

The monitoring items carried out in this paper relying on the project mainly include groundwater level, vertical earth pressure behind the wall, horizontal earth pressure, geogrid strain, deep horizontal displacement and settlement. By analyzing the monitoring data, it is hoped to obtain the earth pressure distribution curve of the revetment wall, the strain distribution law of the geogrid, and the deformation law of the soil behind the revetment and the wall, and evaluate the mechanical performance of the retaining wall and the resistance of the geogrid. The influence of soil pressure and displacement characteristics of the wall is then analyzed to analyze the influence of the geogrid on the stability of the retaining wall.

Fig. 3. Monitoring points arrange of single-layer masonry retaining wall (unit: mm)

2.3 Analysis of test results

2.3.1 Earth pressure analysis

Fig. 4. Relationship between vertical earth pressure and depth of single-layer masonry retaining wall

Fig. 5. Relationship between vertical earth pressure and distance to single-layer masonry retaining wall

Figure 4 shows that the vertical earth pressure has a good linear relationship with the buried depth, and the vertical earth pressure increases linearly with the increase of the buried depth. It can be seen from Figure 5 that the soil pressure distribution at different buried depths is relatively uniform. The reason is : the geogrid can balance the force of the soil body, while limiting the horizontal displacement of the soil body, thereby improving the stability of the retaining wall.

2.3.2 Strain analysis of geogrid

Fig. 6. Strain of geogrid

The maximum strain value of the geogrid at all measuring points in the field test is 1.1%. The maximum allowable strain value of the geogrid used in the project studied in this paper is 3%. The results of the field test show that the geogrid in the test section is in a safe state. It can be seen from Figure 6 that the strain value of the geogrid at the bottom of the fill is significantly greater than that of the geogrid at the top, that is, the force on the geogrid at the bottom of the fill is significantly greater than that on the top. Moreover, the maximum strain value of each layer of reinforcement is mainly distributed at the position of the slip surface. The reason is that“ the retaining wall will produce lateral deformation, and the geogrid exerts the reinforcement and anchoring effect to limit the sliding of the soil”. At this time, the geogrid at the slip surface is most stressed , so the grid strain is the maximum at this place. The grid strain maximum points of each layer are connected to form the shape of the slip surface.

3 Numerical simulation

3.1 Material calculation parameters

Table 1 .Material calculation parameters.

Material name	Elastic Modulus (MPa)	Poisson's ratio	weight (kN·m ³)	Cohesion (kPa)	Internal friction angle (°)	Constitutive relationship
Filling behind the wall	4	0.3	18	14	13	Moore-Cullen
Retaining wall block	2.6×10 ⁴	0.167	24	—	—	Linear elasticity
Retaining wall foundation	2.6×10 ⁴	0.167	24	—	—	Linear elasticity
geogrid	100	0	—	—	—	Linear elasticity

In order to study the influence of the geogrid parameters on the retaining wall, the controlled variable method was used in the numerical simulation to change the geogrid parameters (including the length and spacing of the grid) for numerical analysis.

3.2 Comparative analysis of numerical simulation results and test results

3.2.1 Earth pressure analysis

Relying on the actual engineering, this paper uses Abaqus finite element software to perform numerical analysis on the composite I-shaped masonry retaining wall, and compares the numerical analysis results with the experimental results. At the same time, the method of numerical analysis is used to study the influence of the length and vertical spacing of the geogrid on the stability of the combined I-shaped masonry retaining wall.Finally, based on the results of numerical analysis, provide suggestions for the optimal design of composite I-shaped masonry retaining wall.

Because the retaining wall and bank protection are constant in the length direction, it can be approximated as a plane strain problem. Therefore, this paper uses a two-dimensional model to numerically simulate the composite I-shaped masonry retaining wall. For the convenience of research, in the numerical simulation, the backfill behind the wall is considered to be a homogeneous clay. The constitutive relationship of the soil adopts the Mohr-Coulomb model. The stress-strain relationship of the geogrid is in the elastic stage in the working state, so the constitutive relationship of the geogrid is an elastic model. It is believed that the geogrid can only be tensioned and cannot withstand compressive stress.The model calculation parameters are shown in Table 1.

Fig. 7 Comparison of simulated and measured values of vertical earth pressure on a single-layer masonry retaining wall

Fig. 8. Comparison of simulated and measured values of horizontal earth pressure on a single-layer masonry retaining wall

It can be seen from Figures 7 and 8 that although there are some differences between the numerical simulation value and the measured value, the force law of the soil under the reinforcement of the geogrid can be roughly obtained through the numerical simulation, which verifies the value Simulation reliability.

3.2.2 Strain analysis of geogrid

In the numerical simulation carried out in this paper, a total of 7 layers of geogrids are arranged at different depths. In the analysis, this paper selects 3 layers of geogrids with the same embedded depth as the field test for analysis, and their embedded depths are 0.8 m, 2.4m and 4m correspond to the geogrids of the uppermost, middle and lowermost layers in sequence. According to the simulation results and the actual measured values, a comparison chart of the simulated strain of the geogrid and the actual measured value is made, as shown in Fig9.

Fig. 9. Comparison of simulated and measured strain values of geogrid

It can be seen from Figure 9 that the numerical simulation value of the geogrid is in good agreement with the measured value. The strain law of the geogrid at different buried depths is also different. The strain law of the geogrid at different buried depths is also different. The strain of the geogrid at the buried depth of 0.8m and 2.4m has two peaks. The first peak appears at 0m away from the retaining wall, and the second peak appears at 1m away from the retaining wall. The location of the first peak is also the connection between the grid and the retaining wall panel. It is a weak point and the force is bigger, so the geogrid produces a bigger strain amount at this location. The second peak position characterizes the location of the potential damage surface. The strain of the geogrid at the buried depth of 4m has only one peak, which is at the junction of the grille and the retaining wall panel. This is consistent with the actual measured value, indicating that the potential slip surface at the buried depth of 4m is close to the retaining wall.

3.3 The influence of geogrid parameters on reinforced masonry retaining walls

In retaining wall engineering, limited to the site conditions and economic considerations, geogrids are often placed behind the wall to improve the strength and rigidity of the fill. There are two very important parameters when the geogrid is laid. They are the laying length and spacing of the geogrid. Increasing the layout length and reducing the layout spacing can significantly improve the overall stability of the retaining wall, but many studies have shown that blindly increasing the layout length and layout density has limited effects. Moreover, increasing the laying length means expanding the excavation area behind the wall and increasing the workload of excavation and filling. At the same time, reinforced retaining walls often adopt layered construction, and the increase in layout density will increase too many working procedures and affect the construction progress. Therefore, it has good economic and time benefits to study and determine the optimal laying length and spacing of geogrids.

(1) The influence of the length of the geogrid

In order to study the influence of the length of the geogrid, this paper sets the length of the geogrid as 3m, 4m, 5m, 6m and 7m, and establishes a model for each length to simulate. When analyzing the data, this article uses the relative value data L/H . Therefore, L/H is the length of the geogrid/the height of the retaining wall, which is a relative quantity. Based on this calculation, the L/H values in this paper are 0.3, 0.4, 0.5, 0.6 and 0.7

respectively. The specific change trend can be seen in Figure 10.

Fig. 10. Maximum horizontal displacement of retaining wall under different L/H conditions

Observe the change trend of the curve in Figure 10, when $L/H=0.3$, that is, when the length of the grid is the smallest, the maximum horizontal displacement of the retaining wall is the largest, and then with the increase of L/H , the maximum horizontal displacement of the retaining wall decreases continuously. When $L/H>0.5$, the curve begins to become flat, which shows that the effect of increasing the length of the geogrid cloth to enhance the stability of the retaining wall is no longer obvious. Therefore, considering the influence of economy and construction period, the geogrid should not exceed 0.5 times the height of retaining wall in practical engineering.

(2) The influence of geogrid spacing

In order to study the influence of the geogrid spacing on the stability of the retaining wall, this paper controls the length of the geogrid L to be 5m unchanged, and changes the spacing H_1 of the geogrid, respectively taking $H_1=1.0\text{m}$, 1.5m , 2.0m , 2.5m and 3m . In the analysis of the results, the change of geogrid spacing is represented by H_1/H , and H represents the height of the reinforced masonry retaining wall, which is 10m.

Fig. 11. Maximum horizontal displacement of retaining wall under different H_1/H conditions

It can be seen from Figure 11 that when H_1/H gradually increases from 0.10 to 0.30, the maximum horizontal displacement of the retaining wall gradually increases. This shows that the maximum horizontal

displacement of the retaining wall is affected by the layout density of geogrid. When the layout density decreases, the maximum horizontal displacement of the retaining wall will increase significantly. When H_1/H changes between 0.20-0.30, the curve becomes steeper, which means that when the geogrid layout density is lower than 0.20 ($H_1/H>0.20$), the displacement of retaining wall increases significantly and the stability deteriorates.

Based on the above analysis results, it can be concluded that the optimal parameters of the geogrid layout are around $L/H=0.5$ and $H_1/H=0.2$.

4 Conclusion

Based on field tests and numerical simulations, this paper studies the reinforcement effect of combined I-shaped reinforced retaining wall, and the conclusions are as follows:

(1) Geogrid reinforcement can slow down the potential sliding surface of the fill and move to the inside. The geogrid can effectively limit the horizontal displacement of the soil and increase the stability of the retaining wall. The middle and lower parts of the soil are the main stress areas of the geogrid. It is recommended to use the upper sparse and lower dense layout in the design.

(2) The maximum strain value of the geogrid at all measuring points in the field test is 1.1% less than 3%, which indicates that the maximum force of the reinforcement is far less than the limit value, and the mechanical performance of the reinforcement is not fully utilized.

(3) Through the numerical simulation, the force law of the soil under the reinforcement of the geogrid and the strain curve of the geogrid can be roughly obtained, which verifies the reliability of the numerical simulation.

(4) The two parameters of geogrid layout, L/H and H_1/H , have different effects on the horizontal displacement of the retaining wall. The horizontal displacement of the retaining wall will decrease with the increase of L/H , but increase with the increase of H_1/H . Therefore, in order to improve the stability of the retaining wall, we can increase the length of the geogrids and reduce the distance between the geogrids. According to the analysis results of this paper, the optimal parameters of geogrid layout are around $L/H=0.5$, $H_1/H=0.2$.

References

1. Vidal H. The principle of reinforced earth[J]. Highway Research Record, 1969, 282.
2. WANG Xu, LIU Yitong, LIU Wei. Study of geogrid-reinforced retaining design method of by FEM[J]. Sichuan Building Science, 2013, 39(2):185. (in Chinese)
3. Richardson G N, Lee K L. Response of model reinforced earth walls to seismic loading conditions[J]. Earthquake Resistant Structures, 1974.
4. Claus H. Gobel, Ulrike C. Weisemann. Effectiveness of a reinforcing geogrid in a railway subbase under

- dynamic loads[J].*Geotextiles and Geomembranes*, 1994, 13:91-99.
5. Hong yan. Study on the Application and Stability of Combined I-Shaped Ecological Revetment in Inland Waterway Project [D]. Nanjing: HoHai University, 2018. (in Chinese)
6. YANG Guang-qing, CAI Ying, SU Qian. Testing study on deformation and stress of reinforced earth retaining wall for high embankment[J]. *Chinese Journal of Rock Mechanics and Engineering*, 2003, 22(2): 321 - 326. (in Chinese)
7. CHEN Y K. Model test and numerical analysis of earth pressures on retaining wall [D]. Hangzhou: Zhejiang University, 2001. (in Chinese)
8. Zhang Xiaohua, Sun Chuanyan, Wang Rongxun. On-site inspection and result analysis of ecological flexible retaining wall[J]. *New building materials*, 2005(11):50-52. (in Chinese)
9. LU Yonggang. Research on stress diffusion and deformation characteristics of geogrid reinforced earth retaining wall in high-speed railway[D]. Beijing: Beijing Jiaotong University, 2001. (in Chinese)
10. LI Lihua, SHI Aoning, XIAO Henglin, et al. Model test and mechanical properties study of reinforced earth retaining wall[J]. *Rock and Soil Mechanics*, 2018, 39(12): 360-368. (in Chinese)
11. YANG Guang-qing, ZHOU Yi-tao, ZHOU Qiao-yong, et al. Experimental research on geogrid reinforced earth retaining wall[J]. *Rock and Soil Mechanics*, 2009, 30(1):206-210. (in Chinese)
12. CHEN Xiao-ping, YANG Guang-hua, YANG Xue-qiang. Constitutive relation of soils[M]. Beijing: China Water & Power Press, 2011. (in Chinese)
13. FEI K, PENG J. Detailed explanation of ABAQUS geotechnical engineering example [M]. Beijing: Posts and Telecom Press, 2017. (In Chinese)
14. Zhang Yangyang. Numerical Simulation on Effect of Grid Length on Stability of Reinforced Soil Retaining Wall[J]. *Chongqing Architecture*, 2020, 19(08):36-38. (in Chinese)
15. Wang Zhenjun. Stability calculation and finite element analysis of reinforced earth retaining wall[J]. *Building materials development orientation*, 2017, 15(12):52-54. (in Chinese)