Numerical simulation of the influence of ground fissures on the deformation characteristics of the surface

Yingjie Tian¹, Zhipeng Xu², Hongwei Hu³

¹Yunnan Construction Infrastructure Investment Co., Ltd, Kunming, Yunnan, China
²School of Civil Engineering, Chongqing Jiaotong University, Chongqing, Chongqing, China
³Branch of Anhui Water Conservancy and Hydropower Survey and Design Institute, Bengbu, Anhui, China
*Corresponding author’s e-mail: xufeng8@cmhk.com

Abstract: In order to study the influence of ground fissures on the construction of expressway, a ground fissure (F1) with a strike of NE20°-45° and length of 120km in Yunnan Province is selected as the research object. The FLAC3D numerical software is used to study the characteristics of displacement and stress. The results show that: (1) under normal fault activity, vertical displacement mainly develops hanging wall. (2) The overall variation law of the surface subsidence curve presents an "s" type distribution. (3) The stress of the two plates changes with the fracture activity, which is manifested in the stress increasing area in the footwall and the stress decreasing area in the hanging wall.

1. Research Background

Ground fissures the surface rock and soil are cracked under the action of crustal activities, water, pumping, irrigation, excavation, etc., and a damage phenomenon of cracks of a certain length and width is formed on the ground [1-2]. At present, ground fissures have become one of the major geological disasters in Guangdong [3], which will have serious impacts on engineering construction including railways, highways and buildings [4]. Qiangbing Huang et al. [5] took the Xi’an subway tunnel through the ground fissure active zone as an engineering study, and used a combination of large-scale model tests and finite element numerical simulation calculations to determine the deformation and failure mechanism of subway tunnels with different lining structures under the action of ground fissures. Conducted a systematic study; Based on the disaster mechanism of ground fissures, Qiyao Wang [6] and others analyzed the causes of damages caused by ground fissures to highway engineering, put forward targeted protective measures, and provided valuable opinions on road construction and transportation and maintenance at this stage: According to the characteristics of ground fissures in a certain expressway, Hailong Xing et al. [7] carried out research on the degree of risk based on the analytic hierarchy process, and finally proposed an effective evaluation method for the risk of ground fissures on highway.

Although domestic and foreign scholars have carried out a series of studies on the impact of ground fissures on engineering construction and have achieved fruitful results, there are still insufficient studies on the impact of ground fissures on highway construction in Guangdong. With the development of science and technology, numerical simulation technology has been rapidly developed and widely used in...
the fields of geotechnical engineering and engineering geology [8]. Especially under some large-scale and complex engineering geological conditions, it is difficult to use actual physical similar models to simulate the mechanical properties and evolution laws of rock and soil. Therefore, the rapid development of numerical simulation technology provides new research methods and ideas for studying the impact of ground fissures on engineering construction, which provides effective guidance for actual engineering examples.

2 .Project Overview
In order to study the influence of ground fissures on highway construction, a ground fissure (F1) in Yunnan is selected: the overall strike of the active fault is NE20~45°, and the total length of the fault is about 120km. This fault activity period started from the Mesozoic Era, and mainly concentrated in the Cenozoic period, and continued to be active until the Late Tertiary. Since the Quaternary, the fault activity has continued and the activity intensity is relatively weak.

Table 1. F1 fracture

| Number  | Towards Tendency | Inclination | Feature |
|---------|-----------------|-------------|---------|
| F1      | NE20~30°        | SE          | 60°     | Break  |

The burial depth of the fault is, from bottom to top, the bedrock, silt layer, sandy clay layer, silty clay layer and fill layer, a total of 5 rock layers.

3 .Numerical simulation study on ground fissure characteristics

3.1. Model building
Based on the distribution range of the actual study area, the model was generalized, and finally the size of the numerical calculation model was determined as: 150m×100m×60m, and the thickness of each rock layer was: bedrock 10m, silt layer 20m, sandy clay layer 10m, powder The quality clay layer is 15m, the fill layer is 5m, and the total thickness is 60m.

(1) Boundary conditions of the model: this simulation imposes fixed boundaries in x, y and z directions on the entire model, fixed x=0, x=150; fixed y=0, y=100; fixed z=0. That is, the model is fixed around and on the lower surface, and the upper surface and internal strata can move freely.

(2) Fracture activity of the model: The simulation of the fracture activity of this model is realized through the interface contact surface in FLAC3D. A series of triangular elements in the interface are used to simulate the fracture surface of the model, which can simulate the actual fracture activity more accurately. The location of the fracture is at x=75 in the middle of the model, and the dip angle is set to 60°. The simulation of model fracture activity is to apply a vertical downward velocity to the bottom of the fracture hanging wall. The velocity is v=1×10^-4m/step. In the calculation, 3000 steps are used as a stage, and 4 stages are simulated. The relationship between the fault displacement s, the speed v and the number of running steps n is s=v×n, and four stages are obtained to simulate the vertical fault s=0.3m, s=0.6m, s=0.9m and s=1.2 m.

(3) Calculation parameters of the model: Moore-Coulomb constitutive model is selected for simulation. See Table 2 for specific calculation parameters of each layer.

Table 2 .Model calculation parameter table

| Strata    | Elastic Modulus E/MPa | Poisson's ratio μ | Cohesion c/kPa | Internal friction angle φ° | Density ρ/kg/m3 |
|-----------|-----------------------|-------------------|----------------|---------------------------|-----------------|
| Fill soil | 40                    | 0.2               | 30             | 15                        | 2000            |
| Silty clay| 100                   | 0.35              | 200            | 20                        | 2100            |
| Material     | q (kN/m²) | y (°) | p (kPa) | H (m) | $f_s$ (kPa) |
|-------------|-----------|-------|---------|-------|-------------|
| Sandy clay  | 160       | 0.33  | 160     | 18    | 2150        |
| Silt        | 250       | 0.3   | 0       | 30    | 2200        |
| Bedrock     | 1000      | 0.25  | 2000    | 40    | 2500        |

Fracture contact surface \( K_n=100\text{MPa}, K_s=10\text{MPa}, c=0, \phi=10° \)

The model is divided into 48,000 units and 53,361 nodes.

Figure 1. Schematic diagram of numerical calculation model for fracture

3.2. Vertical displacement characteristics

According to the initial conditions in Figure 2, the vertical displacement cloud diagram of the model under the condition that no fault has occurred, it shows that the vertical displacement of the overlying soil is larger than that of the lower part under the self-weight stress of the model soil when no fault has occurred. The displacement appeared on the hanging wall near the fault zone on the ground surface was about 0.110m. The vertical displacement of the hanging wall at the same vertical depth is greater than that of the bottom wall.

Figure 2. Vertical displacement cloud map before fault displacement

Figure 3 shows the vertical displacement cloud diagram under different dislocations. After the fault occurs, the initial displacement balance is broken. In the footwall of the fracture, the vertical displacement contours changed from dense to sparse; the vertical displacement contours of the hanging wall of the fracture developed from a horizontal distribution to a vertical distribution. The vertical displacement of the bottom wall of the fracture has a small change, while the vertical displacement of the hanging wall of the fracture has a larger change. Among them, when the fracture occurs, the maximum vertical displacement appears on the lower right side of the broken hanging wall.

It can be seen from the figure that as the amount of fault dislocation increases, the contours of the hanging wall of the fault near the fault zone change from sparse to dense, indicating that the difference in soil settlement changes in this area is getting bigger and bigger; On the right, the vertical displacement contours are always relatively sparse, indicating that the settlement changes in these areas are stable.
This corresponds to the differential settlement area and the stable settlement area in the previous experiment.

Figure 3. Vertical displacement cloud map under different fault displacement

10 measuring points were arranged on the ground surface of the model to monitor the vertical displacement at z=60m. It was found that the position of the fault zone extending to the ground surface was at x=40.4m (see Figure 4). The curve as a whole was distributed in an "S" shape. The overall settlement increases with the increase in the amount of dislocation, showing that the bottom wall settlement is smaller and the hanging wall settlement is larger. The settlement range of the footwall is relatively small, only within 7m near the fault zone. When x is within the range of 0~33m, the surface soil remains stable and basically does not change in settlement, and the settlement of the surface does not change with the increase in the amount of fracture; The surface settlement changes within the range are quite different, and the slope of the curve near the fault zone is larger, and the slope far away from the fault zone is relatively low, which means that the difference in settlement at the fault zone is the largest; x is in the range of 116~150m. It also tends to be stable, which is basically equal to the amount of discontinuity. The increase in surface settlement within this range is basically equal and increases linearly with the amount of discontinuity. Therefore, it can be inferred that the strata on both sides are relatively stable, and the possibility of ground fissures is low, and the differential settlement of the strata near the fault zone is relatively large and there is a possibility of ground fissures.

Figure 4. Surface settlement curve
3.3. Analysis of characteristics of vertical stress changes
Before the fault occurs, the soil body maintains the balance of initial vertical stress under the action of its own weight stress. The vertical stress gradually decreases from bottom to top. The maximum vertical stress is 3.74 MPa near the hanging wall fault zone, and the minimum is 0.01 MPa around the surface, as shown in Figure 5.

![Figure 5. Vertical stress diagram before fracture](image)

Figure 5 shows the vertical stress cloud diagram under different discontinuities. It can be seen that when the strata on both sides of the active fault zone are relatively dislocated, the stress redistribution occurs in the soil. The vertical stress of the formation near the bottom fault zone changes greatly. The specific manifestation is that the vertical stress of the foot wall increases, and the vertical stress of the hanging wall decreases, and under different amounts of dislocation, there is a local stress concentration near the upper and lower fault zones. Zone: There is a local stress release zone at the bottom of the broken hanging wall. As the amount of faults increases, the maximum vertical stress in the soil formation also increases. When the fault is 0.3m, the maximum vertical stress is 5.43MPa; when the fault is 0.6m, the maximum vertical stress is 6.28MPa, and at this time, the stress release area at the bottom of the hanging wall is connected with the minimum stress area on the surface; the fault is 0.9 At m, the maximum vertical stress is 6.87 MPa; at 1.2 m, the maximum vertical stress is 7.21 MPa.

![Figure 6. Vertical stress cloud diagram under different fault displacement](image)

Four lateral lines were selected in the middle of the silt layer, sandy clay layer, silty clay layer, and fill layer, namely z=20m, z=35m, z=47.5m, and z=57.5m. Different faults were monitored. Measure the vertical stress of the soil, and its change curve is shown in Figure 8.

Under different burial depths, the vertical stress variation curves show consistency as a whole, but the stress and stress variation amplitude in the shallower stratum is smaller, and the stress and stress variation amplitude in the larger burial depth is larger.
In the same deep stratum, the stress of the upper and lower walls is shown as: a stress-increasing area appears in the vertical stress of the lower wall; a stress-reducing area appears in the hanging wall, \( z = 47.5 \text{m} \) and \( z = 57.5 \text{m} \), local stress appears in the fractured lower wall Lower zone. The curvature of the curve is the largest near the fault zone, indicating that the stress change at the fault zone reaches the maximum. The change of vertical stress is small when the fracture is 0.3m, and the change of vertical stress is more significant as the amount of dislocation increases.

4. Conclusion
(1) Under normal fault activity, the vertical displacement mainly develops the hanging wall. The difference in settlement of the soil near the fault zone is greater, while on both sides, the settlement of the soil in the footwall is smaller; the settlement of the hanging wall is larger, but the difference in settlement changes is smaller.

(2) The overall change law of the surface subsidence change curve presents a nearly "S"-shaped distribution. The overall settlement appears to increase with the increase of the amount of dislocation, which shows that the settlement of the bottom wall remains relatively small, and the settlement of the hanging wall is relatively large.

(3) The fracture activity changes the stress of the two plates, which is specifically manifested as a stress-increasing area on the bottom plate and a stress-reducing area on the hanging plate. The vertical stress of the stratum reaches its maximum near the fault zone, and as the amount of fault dislocation increases, the maximum vertical stress in the soil stratum also increases.
Acknowledgments
The authors would like to acknowledge the financial support of the National Key Research and Development Program of China (2018YFC1504904).

References
[1] Qiang Wu, Peipei. Chen Research status and prospect of ground fissure disasters[J]. The Chinese Journal of Geological Hazard and Control, 2003, 14(1): 22-27.
[2] Xu, F., Yang, C., Guo, Y. et al. Effect of bedding planes on wave velocity and AE characteristics of the Longmaxi shale in China. Arab J Geosci 10, 141 (2017).
[3] Jingming Wang, Changcun Li, Chunmei Wang, et al. Research on the distribution and genesis of ground fissures in China[C] Proceedings of the Sixth National Congress of Engineering Geology. 2000.
[4] Zhaoyu,Zhou, Houyun Zhu, Jianqiang Zhong, Ningsheng,Huang, Qizhong Wen, Xiande Xie. Temporal and spatial distribution characteristics of land geological hazards along the coast of Guangdong[J]. Journal of Tropical Oceanography(1):18-26
[5] Qiangbing Huang. Research on the influence mechanism of ground fissures on subway tunnels and disease control[D]. ChangAn University, 2009.
[6] Qiyao Wang, Zhenwei Jiang, Jianbing Peng. The influence of new active faults and ground fissures on highway engineering and countermeasures[J]. Highway,2006(2):104-108.
[7] HaiLong Xing. Evaluation of the hazard of roadbed geological hazards based on the analytic hierarchy process——Taking a highway ground fissure as an example[J]. Shanxi Transportation Science and Technology, 2016(3):38-40.
[8] Quanwei Bai. Application of Basic Geology in Geotechnical Engineering Investigation[J]. Green Environmental Protection Building Materials, 2017(2).
References

[1] Qiang Wu, Peipei. Chen Research status and prospect of ground fissure disasters[J]. The Chinese Journal of Geological Hazard and Control, 2003, 14(1): 22-27.

[2] Xu, F., Yang, C., Guo, Y. et al. Effect of bedding planes on wave velocity and AE characteristics of the Longmaxi shale in China. Arab J Geosci 10, 141 (2017).

[3] Jingming Wang, Changcun Li, Chunmei Wang, et al. Research on the distribution and genesis of ground fissures in China[C] Proceedings of the Sixth National Congress of Engineering Geology. 2000.

[3] Zhaoyu, Zhou, Houyun Zhu, Jianqiang Zhong, Ningsheng Huang, Qizhong Wen, Xiande Xie. Temporal and spatial distribution characteristics of land geological hazards along the coast of Guangdong[J]. Journal of Tropical Oceanography(1):18-26

[4] Qiangbing Huang. Research on the influence mechanism of ground fissures on subway tunnels and disease control[D]. ChangAn University, 2009.

[5] Qiyao Wang, Zhenwei Jiang, Jianbing Peng. The influence of new active faults and ground fissures on highway engineering and countermeasures[J]. Highway, 2006(2):104-108.

[6] Hailong Xing. Evaluation of the hazard of roadbed geological hazards based on the analytic hierarchy process——Taking a highway ground fissure as an example[J]. Shanxi Transportation Science and Technology, 2016(3):38-40.

[7] Quanwei Bai. Application of Basic Geology in Geotechnical Engineering Investigation[J]. Green Environmental Protection Building Materials, 2017(2).