



Study of the deformation mechanism of the Gaoliying ground fissure

G. Cheng¹, H. Wang¹, Y. Luo², and H. Guo¹

¹China Institute of Geo-environment Monitoring, Beijing 100081, China

²Beijing Institute of Geo-environment Monitoring, Beijing 100195, China

Correspondence to: G. Cheng (chenggm@mail.cigem.gov.cn)

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Abstract. The Gaoliying ground fissure in Beijing has caused building cracking and road damage, and has seriously influenced city construction. Based on investigations and trenching, the influences of the fault and the variation of groundwater levels on the formation mechanism of the Gaoliying ground fissure were investigated by using FLAC3D. The results indicated that (1) the surface location of Gaoliying fissure is controlled by the underlying normal fault activity, and over pumping further exacerbates development of the ground fissure; (2) when the groundwater level declines, obvious differential settlement occurs at both sides of the ground fissure, in which greater settlement occurs in the vicinity of the hanging wall, the greater the distance from the hanging wall, the smaller the ground subsidence, however smaller ground subsidence occurs in the vicinity of the footwall, the greater the distance from the footwall, the greater the ground subsidence; (3) the vertical velocity of the ground fissure triggered by the fault activity and groundwater decline ranges from 15.5 to 18.3 mm a⁻¹, which is basically in line with the monitoring data. The fault activity contributes about 28–39 %, and the groundwater contributes about 61–72 % to the deformation of the ground fissure, respectively.

1 Introduction

Ground fissures are common in many parts of the world, and have been particularly well documented in the United States and in China (Holzer, 1980; Zellmer et al., 1985; Peng, 2012). Many fissures appear similar to those caused by groundwater withdrawal and related ground subsidence (Lister and Secrest, 1985; Lee et al., 1996). In China, the earliest ground fissures were detected at the end of 1950s (Peng et al., 2013). Now ground fissures have been a main geological hazard developed in north China (Wang, 2000; Wang et al., 2001), especially in Gaoliying district in Beijing, which has led to great losses to local economies and has created a large potential danger to human living (Jia and Guo, 2007).

Jia (2010) and Jia et al. (2011) suggests that the Gaoliying ground fissure is controlled by the Gaoliying fault, and its formation is the result of fault creep deformation and the differential settlement caused by groundwater recession. However, there are still some critical problems not yet solved, for example, How does the activity of underlying faults generate

and aggravate the formation and the activity of the ground fissures? What important roles do the tectonic activity and the over-pumping play in the formation of the ground fissures? The influence of fault activities and the groundwater level changes on the Gaoliying fissure based on the measured data was simulated using FLAC3D in this paper. The results provide insight as to the specific contribution of fault activities and groundwater on ground fissure formation, and infers the mechanism for deformation of the fissure.

2 Outline of Gaoliying ground fissure

The Gaoliying fissure in Beijing was first discovered in the 1990s, and the fissure trend is approximately from northeast 45° to northeast 60°, which is consistent with the underlying Huangzhuang–Gaoliying fault. It extends north-eastward from the Xiwang Village to the North sixth ring road (Fig. 1). The fissure has a length of about 6000 m, with a width ranging from a few millimeters to hundreds of millimeters, in which the maximum width is 200 mm. The obvious ground

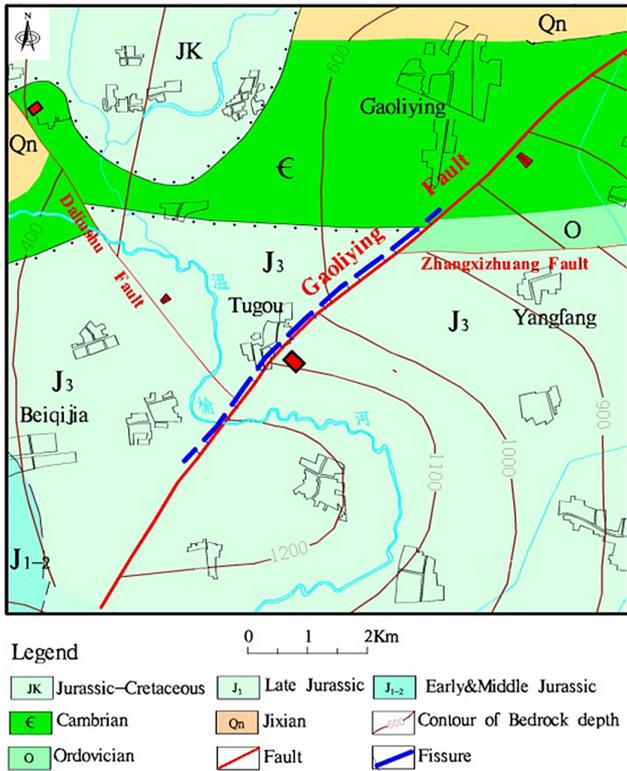


Figure 1. The plan distribution map of Gaoliying fissure and fault.

dislocation occurred at both sides of the fissure, in which the northwest is higher than the southeast, and has caused buildings cracking and has destroyed roads. The data from a ground fissure monitoring station shows that the maximum vertical displacement rate of Gaoliying fissure is 18 mm a^{-1} .

3 Geological background

The Gaoliying fault is an important active fault in the Beijing plain area. Its trend is NNE with a length of 132 km. The fault is the main control fault of the west boundary of Beijing depression in the Tertiary, and Shunyi and Huairou secondary depressions were formed during the Quaternary period. The fault is a normal fault with dip-slip characteristics.

According to the characters of the Quaternary kinematics analysis, the Gaoliying fissure is divided into three parts: the Miaocheng–Gaoliying section (North section, 40 km), the Huangzhuang section (Middle section, 52 km), and the Laishui section (South section, 40 km). The Gaoliying fissure is within the Huangzhuang section. Shallow seismic exploration reveals that the fall of the Quaternary system on both sides of the fault near Gaoliying fissure ranges from 140 to 280 m. The seismic exploration at Tugou village indicates that the thickness of the Quaternary sediments at the footwall and hanging wall is respectively 460–500 and 660–740 m, in which the thickness difference on both sides of the

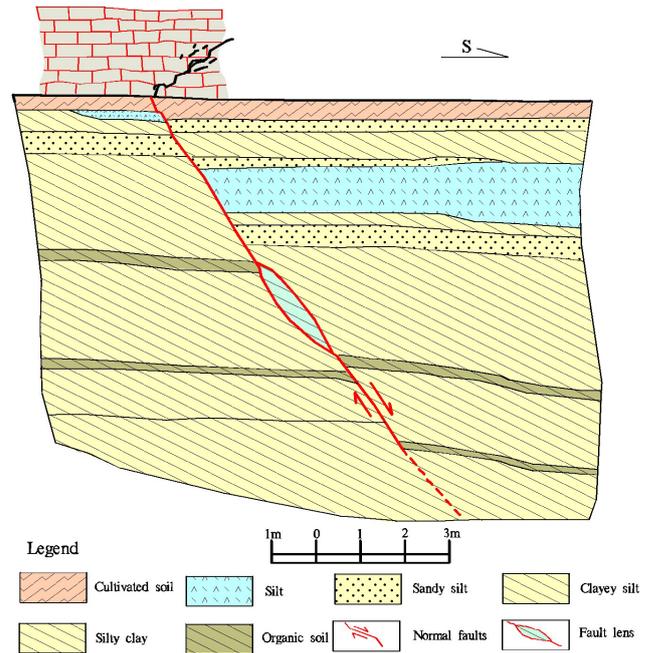


Figure 2. The profile of Gaoliying ground fissure according to trench data.

fault is 200–240 m. The Gaoliying fault location corresponds to the Gaoliying ground fissure. An exploratory trench disclosed that the dislocation distance of the fault at the surface layer is much as 3.56 m (Fig. 2). Boring data revealed that the dislocation distance of fault in the shallow strata is smaller, whereas the dislocation distance of fault in the deep strata is larger. The dislocation distance of fault at the depth of about 50 m is approximately 8 m.

The study area is located on the Wenyu Alluvial Fan plain area, its surface is covered with Quaternary strata. The deposit is relatively simple, and is dominated by fluvial sediments. Table 1 shows the results of geophysical exploration data on both sides of the fault and bedrock bench mark data acquired by the ground settlement monitoring station on both sides of ground fissures.

4 Numerical model

4.1 Conceptual model

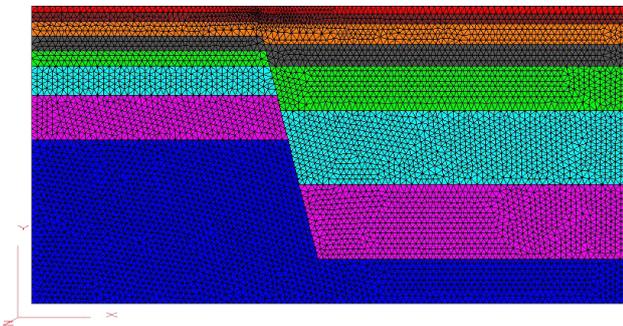
The numerical model is 2000 m in X direction, 1000 m in Y direction and 20 m in Z direction. The model contains 11 440 elements and 11 886 grid points (Fig. 3). Horizontal translation is confined at the lateral boundary and vertical translation in the footwall is confined, whereas vertical translation in the hanging wall is free at the bottom boundary in the model.

Table 1. The simplified strata used in the numerical model.

Stratum name	Silty clay	Silt	Sand	Silty clay	Sandy and silty	Silty clay	Sandy and silty	Bedrock
Thickness of hanging wall (m)	25	35	70	70	150	250	250	150
Thickness of footwall (m)	20	30	50	50	50	100	150	550
Separation of the hanging wall and footwall top (m)	0	5	10	30	50	150	300	400

Table 2. The physical and mechanical parameters of each stratum in the model.

Material	Density (kg m^{-3})	Elastic modulus (GPa)	Poisson's ratio	Cohesion (kPa)	Strength of extension (kPa)	Internal friction angle ($^{\circ}$)	Dilatancy angle ($^{\circ}$)
Silty cla	1750	0.05	0.35	50	20	20	10
Silt	1850	0.06	0.33	40	10	22	10
Sand	1950	0.1	0.3	10	5	25	10
Silty clay	1850	0.2	0.33	50	20	22	10
Sandy and silty	1950	0.5	0.3	30	10	20	10
Silty clay	1950	0.5	0.3	60	30	24	10
Sandy and silty	2000	0.8	0.3	40	20	21	10
Bedrock	2500	10	0.25	10 000	3000	40	10
Fracture surface	1850	0.1	0.2	2	0.2	0	0

**Figure 3.** Numeric simulation structure of Gaoliying fissure.

4.2 Material parameters

In order to simplify the calculation, the Mohr–Coulomb constitutive relation is used for the analysis, and parameter characteristics of different materials are shown in Table 2. In addition, the fracture surface is treated as a weak interface, and its material parameters are separately set.

4.3 Modelling schemes

Based on the bedrock bench mark data from Tianzhu monitoring station and the Baxianzhuang monitoring station on both sides of the Gaoliying fissure, the annual differential settlements are 8, 6.5, 4.8, and 6.7 mm respectively between 2009 and 2012, which indicates that bedrock on both sides of the fault has been in a state of activity, in which the hanging wall declines relative to the footwall. The long-term ground-

water observation hole near the Gaoliying fissure shows that the groundwater level is about 20 m, and the rate of decline of the water level can reach 2 m a^{-1} .

Therefore, three kinds of modeling schemes are considered in this simulation, i.e., the relative decline rate of bedrock between the hanging wall and the footwall is 4.8 mm a^{-1} (Scheme 1) and 8 mm a^{-1} (Scheme 2), and the groundwater decline rate is 2 m a^{-1} (Scheme 3).

4.4 Simulation results

Figures 4 and 5, show that the surface location of the ground fissure is controlled by the underlying normal fault, and it is in agreement with the fault. When the activity velocity of the bedrock inside the fault is 4.8 mm a^{-1} , the maximum differential settlement of the ground fissure is 4.4 mm a^{-1} ; when the activity velocity of the bedrock inside the fault is 8 mm a^{-1} , the maximum differential settlement of the ground fissure is 7.2 mm a^{-1} (Fig. 6).

From Fig. 6, it can be seen that when the groundwater level declines, subsequent differential settlement occurs on both sides of the ground fissure, in which greater ground subsidence occurs in the vicinity of the hanging wall. The greater the distance from the hanging wall the smaller the ground subsidence, however small ground subsidence also occurs in the vicinity of the footwall where the greater the distance from the footwall, the greater the ground subsidence, and the maximum differential settlement of the ground fissure is as much as 11.1 mm.

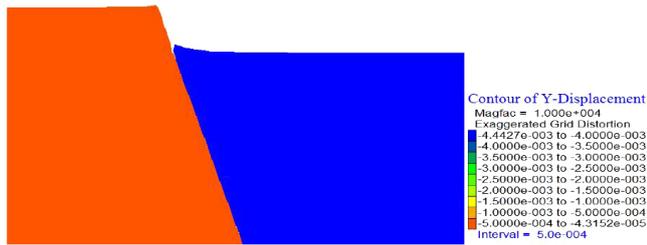


Figure 4. The annual settlement in scheme 1 (scaled up to 10 000 times of the original).

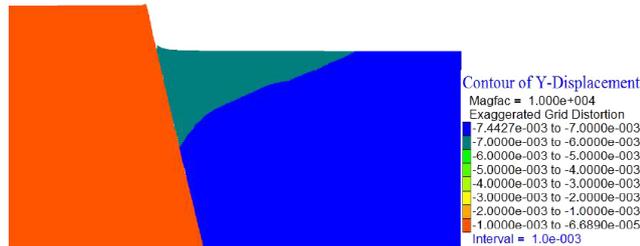


Figure 5. The annual settlement in scheme 2 (scaled up to 10 000 times of the original).

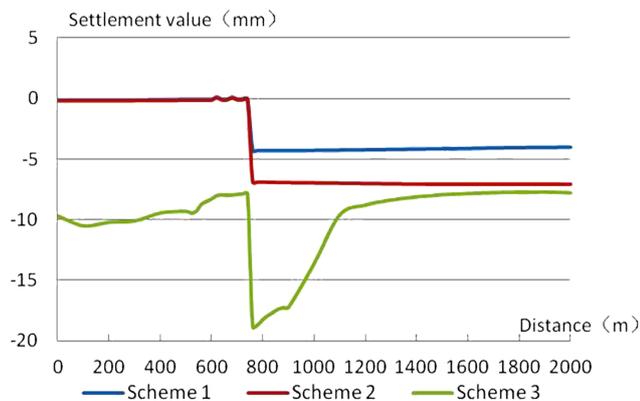


Figure 6. The annual ground settlement at both sides of the ground fissure under different schemes.

The vertical velocity of the ground fissure triggered by the fault activity and over pumping (groundwater level decline) can reach to $15.5\text{--}18.3\text{ mm a}^{-1}$, which is basically in line with the monitoring data. In which the fault activity contributes about 28–39 %, and the groundwater contributes about 61–72 % to deformation of the ground fissure.

5 Conclusions

1. The surface location of the Gaoliying fissure is controlled by the underlying normal fault activity. Differential settlement occurs at both sides of the fault due to the fault activity, which induces the formation of ground

fissure, and over pumping further exacerbates development of the ground fissure.

2. When the groundwater level declines, differential settlement occurs on both sides of the ground fissure, and greater settlement occurs in the vicinity of the hanging wall. The greater the distance from the hanging wall, the smaller the ground subsidence, however small ground subsidence also occurs in the vicinity of the footwall and the greater the distance from the footwall, the greater the ground subsidence.
3. The vertical velocity of the ground fissure triggered by the fault activity and groundwater decline ranges from $15.5\text{ to }18.3\text{ mm a}^{-1}$, which is basically in line with the monitoring data. The fault activity contributes about 28–39 %, and the over pumping contributes about 61–72 % to the deformation of the ground fissure, respectively.

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