Activity Characteristics and Safety distance of Gaoliying Ground Fissure in Beijing

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Abstract. In all ground fissures in Beijing, Gaoliying Ground Fissure has characteristics of highly activity, and it cause serious damages on constructoins. With the distribution as well as the development of land subsidence and the change of the groundwater level, a series of work has been conducted to explain the mechanism of the formation of Gaoliying Ground Fissure. For example, field damage investigations and trench observations were used to define the affected distance of ground fissure; three-dimensional deformation was monitored to determine active characteristic of ground fissure. This paper points out that Gaoliying ground fissure is controlled by Huangzhuang-Gaoliying Fault, which mainly moves in the vertical direction. The rapid decrease of the ground water level greatly increases the development of ground fissure. The distance of damaged zones affected by ground fissure in the hanging-wall of the fault reaches 49.5m, and the distance of damaged zones in the footwall of the fault is 17.5 m. A suggested safety distance of type-one and type-two buildings is 100 m. For type-three buildings, the suggested safety distance is 80 m.

1 Introduction

Ground fissure is a progressive geological disaster which develops slowly. A lot of regions in many countries have ground fissures, such as the USA, Mexico, Japan, countries in East Africa, *etc* [1]. In China, ground fissures are also found in many cities, such as Xi'an, Datong, Suxichang region, Hengshui, and Xingtai. The USA began the study of ground fissures in the Pikachu Basin, Arizona, in 1927. Three viewpoints have been formed to explain the mechanism of fissures: 1. the ground fissure was caused by structure activities; 2. the ground fissure was caused by groundwater exploitation; 3. the ground fissure was caused both by structure activities and groundwater exploitation. Most people believe that structure activities play the most important role in causing ground fissures, and the influence from groundwater exploitation is less important. However, whether the ground fissure is caused by ground water is still in hot discussion [2, 3].

Ground fissures are formed by vertical displacement or horizontal extension. They always bring about differential subsidence between two sides of the fissure, which is the reason of damages for traffic channels and facilities. Ground fissures can not only damage the civil construction, but also threaten the safety of people's lives and properties [4, 5]. It thus necessary to accurately determine the safety distance and activity characteristics of ground fissures when conducting civil construction plans [6-8].

In the 1990s, the ground fissure was found in Gaoliying, Beijing. A large number of buildings along this fissure were damaged. A series of work has been carried out to determine the safety distance and activity characteristics of the ground fissure. For example, field work was conducted to investigate affected distance of damages, trenches were set to observe deformation characteristics of layers and relations between upper layers and underlying fault, a ground fissure monitoring station in Xiwanglu Road was established to monitor active characteristics of the fissure.

This paper proposes a suggested safety distance for constructions, which can be used in the prevention and control work of ground fissures in Beijing.

2 Distribution of Gaoliying ground fissure

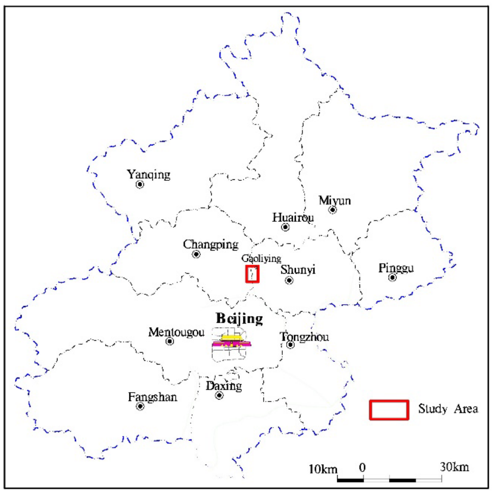

Fig. 1. Location of Gaoliying.

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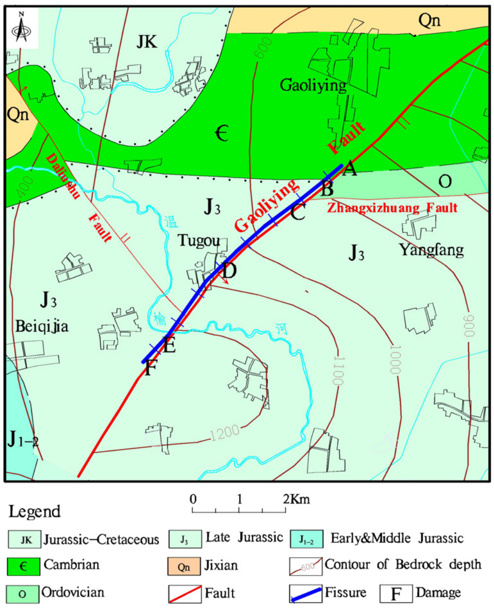

Fig. 2. Distribution of Gaoliying ground fissure and fault.

Gaoliying ground fissrue was firstly found in the 1990s. This ground fissure starts from Baxianzhuang Villa and ends to Gaoliying School. It goes along the north-east direction and pass through Tugou village, Tangzitou village, and Xiwanglu village (see fig. 1 and fig 2).

As shown in fig. 2, The total length of Gaoliying ground fissure is close to 7km. Damages on the surface reveal that the ground fissure mainly moves in the vertical direction. The right part (the south-east side of the terrain) of the fissure has a relative downward trend. The largest steep slope on the surface is 53 cm in the woodland on the north side of Tangzitou Village.

Fig. 3 shows five typical pictures of damages caused by Gaoliying Ground Fissure.

The farmhouse in fig. 3C was constructed in 1970 and deconstructed in 2012. The extension direction of the ground fissure is north-east 75° (NE75°). As illustrated, the wall of the farmhouse was seriously distorted like a dough. Vertical deformation and numbers of cracks distributed from top to bottom. Measurements indicated the height of the right wall (the wall in the hanging-wall side of the fissure) is 18.6 cm lower than the height of the wall in the left side. The deformation rate of the height of the wall in the right side is 4.7 mm/a, whereas the deformation rate is much smaller in the left side. The maximum distance between the fissure and the place where the deformation occurs is 19.5 m in the hanging-wall and 17.5 m in the footwall of the fissure.

The villa in fig. 3F was constructed in 1996 and unoccupied now. As shown, the pavement in front of the villa has been deformed as a result of the rise in the right side (the part in the hanging-wall of the fissure). The surface of the pavement has been destroyed by two main cracks. One crack extends to the surface of the yard of this villa, which has the same extension direction as the main ground fissure. The vertical subsidence in the hanging-wall of the fissure is 6.3 m with a deformation rate of 4.5 mm/a.

3 Activity Characteristics of Gaoliying Ground Fissure

The activity characteristics of ground fissures are often studied from the spatial perspective and from the temporal perspective.

From the spatial perspective, damages to the surface and buildings are mainly limited in a zone along the ground fissure, where severe damages on pavements or in buildings can be easily observed. From the temporal perspective, the deformation and the damage gradually increase with the development of the ground fissure. When activities of the ground fissure slow down or stop, damages will stop, and deformations will reach to stable.

According to the investigation, the ground fissure along Huangzhuang-Gaoliying Fault has following spatial and temporal characteristics:

When we Consider the characteristics of single-point failure, buildings along Gaoliying ground fissure show a phenomenon that their foundations and walls relatively fall in the southeast side. On the contrary, foundations and walls in the west side rise and horizontally twist with a right-handed feature. This phenomenon is consistent with the characteristics of Huangzhuang-Gaoliying

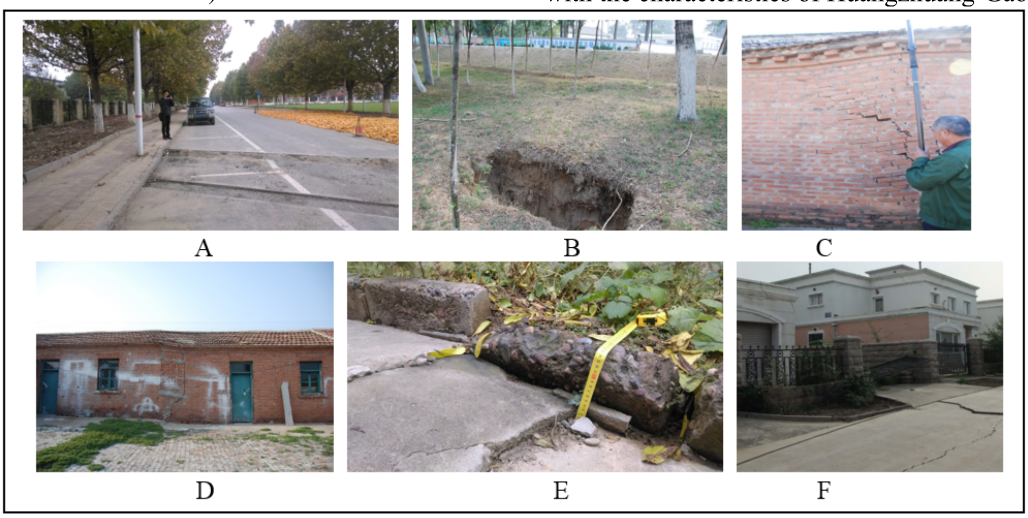

Fig. 3. Typical pictures of damages caused by Gaoliying ground fissure.

Table 1. Characteristics of damages by the ground fissure in selected locations

Location	Direction (NE)	Affected depth in the footwall wall (m)	Affected depth in the hanging wall (m)	Vertical displacement (cm)	Activity rate (mm/a)
8, 1st Lane of Xiwanglu Road	63°	8.7	23.91	6.5	7.2
9, 2nd Lane of Xiwanglu Road	75°	17.43	19.47	18.6	4.7
Woodland in the north of Tangzitou village	71°	13.75	21.7	4	13.3
Huadu Chicken Factory	39°	5	35.66	19	7
Paper factory in Tugou village	8°	-	49.51	0.9	4.5
Clinic in Beiqijia Town		-	28.3	-	-
0808, Baxianzhuang Villa	23°	-	-	6.3	4.5

Fault that the part in the southeast wall (hanging-wall) falls and the part in the northwest wall (footwall) rises and twists.

When we consider the characteristics of damages in a general point of view, the ground fissure mainly moves vertically. The deformations of tension and twist are relatively insignificant. According to measurements, vertical difference of displacement ranges from a few centimetres to a dozen centimetres, and the maximum displacement is 53 cm in Tangzitou Village. The northwest part of the fissure is relatively flat with less obvious rises. The southeast part sinks with slight twists.

The activity rate shown in Table 1 is calculated by the vertical displacement and the time. As shown, the maximum activity rate is 18 mm/a, and the minimum activity rate is 4.5 mm/a. The activity rate gradually increases and causes deformations and damages of farmhouses and Beijing-Chengde Expressway, which indicate that the ground fissure along with Huangzhuang-Gaoliying Fault is still in activity.

More than 30 trenches were excavated between 2007 and 2010 to investigate characteristics of Gaoliying Ground Fissure. Table 2 gives data measured from typical trenches. As shown, the dip angle of the fracture ranges between 60° and 81°. The width of the main fracture ranges between 0 and 7.72 m, which is accompanied by several associated sub-fractures. The vertical displacement of the same layer on both sides of the fracture ranges between 0.4 and 3.21 m. The width of the deformation zones is approximately 25 m. Some fractures extend to the surface and form ground fissures.

The extension direction and the attitude of the main fracture is in accordance with bedrock fault, which provides an evidence that the development of the ground fissure is controlled by the bedrock fault.

The direction of TC11 trench is SW265°. The Cross-section of TC11 trench is shown in Fig. 4. Two positive fractures extend from top to bottom. The main fracture goes in the direction of NE62º. Its attitude is SE∠81°.

Table 2. Characteristics of ground fissures observed in trenches

No.	Direction	Fracture attitude	Direct displacement (m)	Drag deformation (m)	Vertical displacement （m）
Trench in 2007	47°	137°∠60°	-	-	1.56
TC 1	65°	155°∠80°	1.24	2.32	3.56
TC 3	73°	163°∠60°	0.41	-	-
TC 5	30°	120°∠76°	3.21	>0.3	>3.51
TC 6	-	-	0.29	/	-
TC 7	52°	142°∠63.5°	0.56	>0.06	>0.62
TC 8	56°	146°∠67°	0.48	-	-
TC10	73°	163°∠76°	>1.18	-	-
TC11	62°	152°∠81°	1.71	1.25	2.96
TC12	65°	155°∠76°	2.04	1.02	3.06
TC13	40°	130°∠81°	0.75	-	-
TC15	57°	147°∠76°	0.76	>0.29	>1.05
TC17	-	-	0.1	0.3	0.4

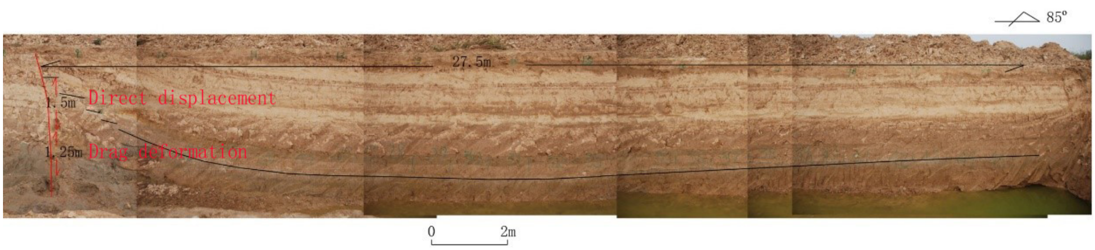

Fig. 4. Cross-section of TC11 trench.

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According to geotechnical characteristics and formation era, cross-section of TC11 trench can be divided into 10 soil layers from top to bottom: artificial fill layer, clay layer, silty clay layer, clay layer, fine sand layer, silt layer, clay layer, silt layer, silty clay layer, and clay layer. In the 4th layer, the vertical difference of the clay layer in two sides of the fracture reaches to 0.72 m. In the 5th layer, the vertical difference of the fine sand layer is 0.39 m. In the 6th layer, the vertical difference of the silt sand layer is 0.12 m. In the 7th layer, the vertical difference of the clay layer is 0.08 m. The top artificial layer has no vertical difference. The 4 layers, 5th to 8th layers (fine sand layer, silt layer, clay layer and silt layer), are broken by the fracture. A small amount of soil and rock blocks are contained in the gap of the main fracture. Associated sub-fractures cause smaller displacement in 5th to 8th layers, which ranges between 0.1 and 0.2 m.

In the hanging wall of the fracture, a remarkable thin layer with dark organics well distinguishes the 3rd layer and the 4th layer.

Affected by the fracture, layers were broken and moved four times, forming 1.5 m accumulated displacement, 1.25 m drag deformation, and 2.96 m vertical displacement (1.71 m direct displacement and 1.25 m drag deformation). As shown in fig. 4, deformation width in the hanging wall is 25.5 m, and deformation width in the footwall is 9 m

Xiwanglu Road Trench was excavated in 2007. It goes in the direction of SN, with 20 m length, 9 m width, and 8.4 m depth.

As shown in fig. 5, the stratum can be divided into 12 layers based on geotechnical characteristics. Two main normal fractures distribute in the cross-section. The left one is the main fracture, which extends to the surface of the terrain and displaces the whole stratum with the difference of 1.56 m. The right one is the sub-fracture, which extends to the sand layer (10th layer). Thickness and the number of layers in two sides of the main fracture are different. The top of the 6th layer in the right side of the main fracture shows is zigged shape. The top of the 6th layer in the left side shows a decreasing trend

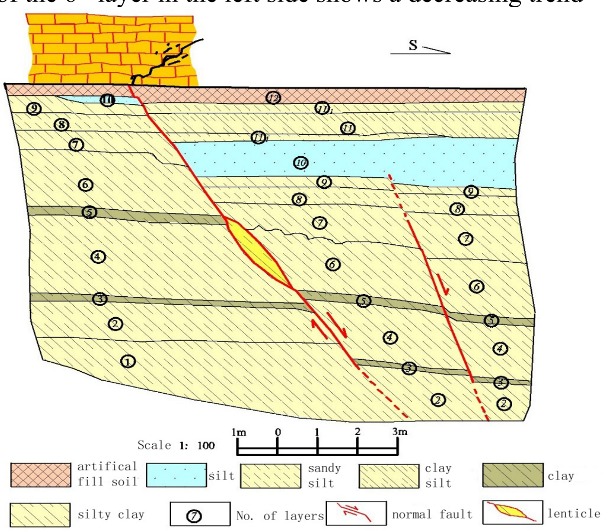

Fig. 5. East cross-section of Xiwanglu Trench.

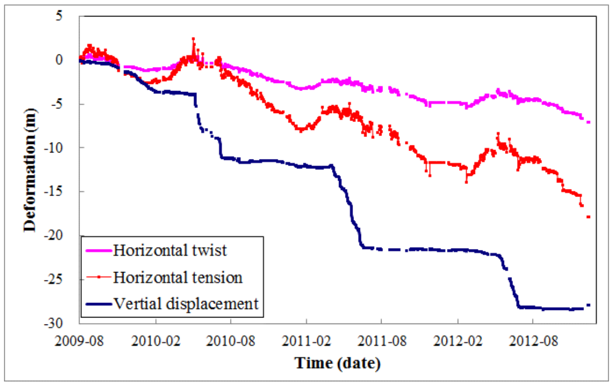

Fig. 6. The accumulative curves of three-dimensional activities of the ground fissure.

from left to right. These two phenomena indicate that the 6th layer was cut and severely dragged by the geological stress.

Xiwanglu Road Ground Fissure Station was established To monitor the activity characteristics of Gaoliying Ground Fissure. According to analysis of monitored data, Gaoliying Ground Fissure has three-dimensional activity characteristics. In the vertical direction, the hanging wall of the fissure shows a relative rising trend. In the horizontal direction, the fissure shows characteristics of right-handed twist and horizontal extension. From August 2009 to November 2012, the ratio of horizonal twist, horizonal extension, and vertical displacement is 1: 2.5: 4.6. The accumulated deformations of the horizontal twist, the horizontal extension, and the vertical displacement are 6.1 mm, 15.8 mm, 28.35 mm, respectively. Therefore, the deformation of the vertical displacement is larger than other two deformations. The horizontal twist has the smallest deformation in three-dimensional activities.

The three-dimensional activity characteristics of Gaoliying Ground Fissure are consistent with that of Huangzhuang-Gaoliying Fault, which is the evidence that the ground fissure is controlled by the fault.

The activity of Gaoliying Ground Fissure shows time regularity. From May to December, the activity is controlled by right-handed twist and extension, whereas it changes to be controlled by left-handed twist and contraction from January to April. Vertical displacement is larger from April to June. Vertical displacement decreases in other months.

4 Causes of Gaoliying Ground Fissure

Field investigations and observations from trenches indicate that the distribution of Gaoliying Ground Fissure agrees with the surface location extended from Huangzhuang-Gaoliying Bedrock Fault.

Many researches provide different causes of Gaoliying Ground Fissure [9-12]. This paper holds the opinion that this fissure is caused by compound factors. It is mainly controlled by Huangzhuang-Gaoliying Bedrock Fault and be considered as a surface reflection of the fault. The development of the ground fissure is the result of the combination of creeping deformation of the fault and land differential subsidence caused by groundwater exploitation.

5 Safety distance for constructions

Human effects can rarely influence geo-tectonic actions. Gaoliying Ground Fissure is controlled by Huangzhuang-Gaoliying Fault; therefore it is better to set a safety distance for constructions along the ground fissure. At present, scientists in Xi'an city did a lot of researches on safety distance between constructions and fissures [13]. Government has issued a local regulation- "Xi'an Ground Fissure Site Survey and Engineering Design Regulation" (DBJ61-6-2006), which gives safety distance for different constructions. The regulation defines that safety distances for type-one buildings (buildings with floors more than 19) are 40 m in the hanging wall side of the fissure and 24 m in the footwall side. For type-two buildings (buildings with floors between 10 to 18), safety distances are 20 m in the hanging wall side and 12 m in the footwall side. This regulation has been applied in civil and railway constructions.

The safety distance for constructions along Gaoliying Ground Fissure is determined according to field investigations and observations in trenches (see table 3). The distances affected by ground fissures are 49.5 m in the hanging wall side and 17.4 m in the footwall side. According to the published regulation, the safety factors are 1.5 for type-one and type-two buildings and 1.2 for type-three buildings (buildings with floors less than 9). Thus, the safety distances for type-one and type-two buildings are 74.27 m in the hanging wall side of the fissure and 26.14 m in the footwall side. For type-three buildings, safety distances are 59.4 m in the hanging wall side and 20.9 m in the footwall side.

Zones within the safety distance can be built with traffic roads, squares, gardens, and so on.

6 Conclusions

Gaoliying Ground Fissure is controlled by Huangzhuang-Gaoliying Fault with three-dimensional active characteristics. The largest deformation appears in

Table 3. Distance between constructions and the fissure

	No.	Distance（m）		
		Hanging wall	Foot-wall	Total
Trenches	TC1	7.2	25	32.2
	TC11	9	25	34
	TC12	4.5	24.5	29
Field work	1. Lane of Xiwanglu Rd.	8.7	23.91	32.61
	2. Lane of Xiwanglu Rd.	17.43	19.47	36.9
	Tangzitou Village	13.75	21.7	35.45
	Chicken Factory	5	35.66	40.66
	Paper factory	-	49.51	49.51
	Clinic in Beiqijia Town	-	28.3	28.3

the vertical displacement, and the twist has the smallest deformation. The deformation of the horizontal extension is smaller than vertical deformation and larger than twist deformation.

The distance of the width influenced by the ground fissure is 67 m. A suggested safety distance for type-one and type-two buildings is 100 m. For type-three buildings, the suggested safety distance is 80 m.

The safety distance is determined by field investigations and observations of trenches. It thus necessary to do further research to verify the value of the safety distance. Infrastructures that are hardly to be moved to avoid the influence of ground fissures, such as expressways, rail ways, and tunnels, should be carefully treated during construction. Their protections will be studied in our future work.

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