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Physical simulation of ground fissures triggered by underground fault activity

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ABSTRACT

Numerical modeling and physical simulation experiment are two important steps to investigate the stress and strain fields of overlying strata, but sometimes it is very difficult to do the test of the physical experiment on a large-scale soil sample due to the financial consideration and the available test site. To investigate the features of the ground fissures prevailing in Xi'an City, we undertook in this study a series of physical simulation tests on the large-scale soil sample to analyze the stress and displacement fields caused by the underlying normal fault activity. Comparing with the fracturing modes of the ground fissures and the failure patterns of construction building, it is evident that the experiment results coincide with the failure patterns of the building, but not with the fracturing modes of the ground fissures, which indicate that the ground fissures in Xi'an may be an old fracture surface having already spread to superficial layer covered by a very thin layer of loose soils, and the groundwater over-pumping is just a factor to make them exposed on the ground surface.

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. Many fissures appear similar to those caused by groundwater withdrawal and related ground subsidence. Yet, in the United States, some of the earliest-reported fissures occurred in the late 1920s at the Goose Creek oil field near Houston, Texas and therefore were attributed to large-scale hydrocarbon withdrawal (Pratt and Jonhson, 1926). In the next few decades, ground fissures and subsidence were widely recognized in much of the western United States. Based on the investigations, for example, of Feth (1951), Schumann and Poland (1970), Holzer (1980) and Lofgren (1978), several mechanisms were invoked to explain the mechanism of fissure formation stemming from groundwater pumping. Some fissures are relatively linear, coincident with relatively steep subsurface bedrock slopes (Schumann and Poland, 1970) or with underlying faults. Fissures in the Las Vegas, Nevada area similarly generally follow the trend of underlying faults and only a few form classic concentric circles around pumping wells (Bell et al., 1992).

In China, the earliest ground fissures were found in the end of 1950s. Now ground fissures have been a main geological hazard developed in north China (Yi, 1984; Zhang, 1990; Peng et al., 1992, 2006; Zhao and Wang, 1995; Lee et al., 1996; Li et al., 2000; Wang, 2000; Wang et al., 2001), especially in Fenwei depressed Basin, which costs great losses to local economics and has big potential danger to human living (Wang, 2000; Wang et al., 2001). Unfortunately Xi'an city is located at the above Fenwei depressed Basin and is the most famous city worldwide with geo-hazard (Lee et al., 1996). Since 1950s there have been about 14 ground fissures discovered in Xi'an city (Figure 1), with a total length over 100 km and a coverage area up to 150 km^2. These ground fissures induce a series of geo-hazards to civil construction, which make buildings broken, machines stalled, roadway distorted and pipeline burst, etc.

In a plan view the ground fissures in Xi'an city have obvious features, such as directional extension, banding distribution, uniformly-spaced location. In section they have the features of dislocation synchronism and multi-level combination (Figure 2). Most ground fissures are composed of many sub-fissures or branching fissures and the large-scaled sub-fissures are often developed on hanging wall. The direction of principal strike of main ground fissures is northeastern with southeastern tendency and the dip angle is about 80°. The ground fissures have the intermittent extension features, and the extension length of each ground fissure can be up to several or more than ten kilometers. The activity modes of ground fissures in Xi'an city are manifested as creep, with relatively falling of southern side (hanging wall) and rising of northern side (footwall) of main ground fissure. On the contrary, the activity of sub-fissures is shown as relatively falling of northern side (hanging wall) and rising of southern side (footwall). Fig. 3 shows the profile characteristics of Xi'an ground fissures.

The following are two different standpoints on the generated mechanisms about ground fissures in Xi'an city: (1) they are induced by large-area ground settlement due to groundwater over-pumping (Yi, 1984), because ground fractures will originate in the differential

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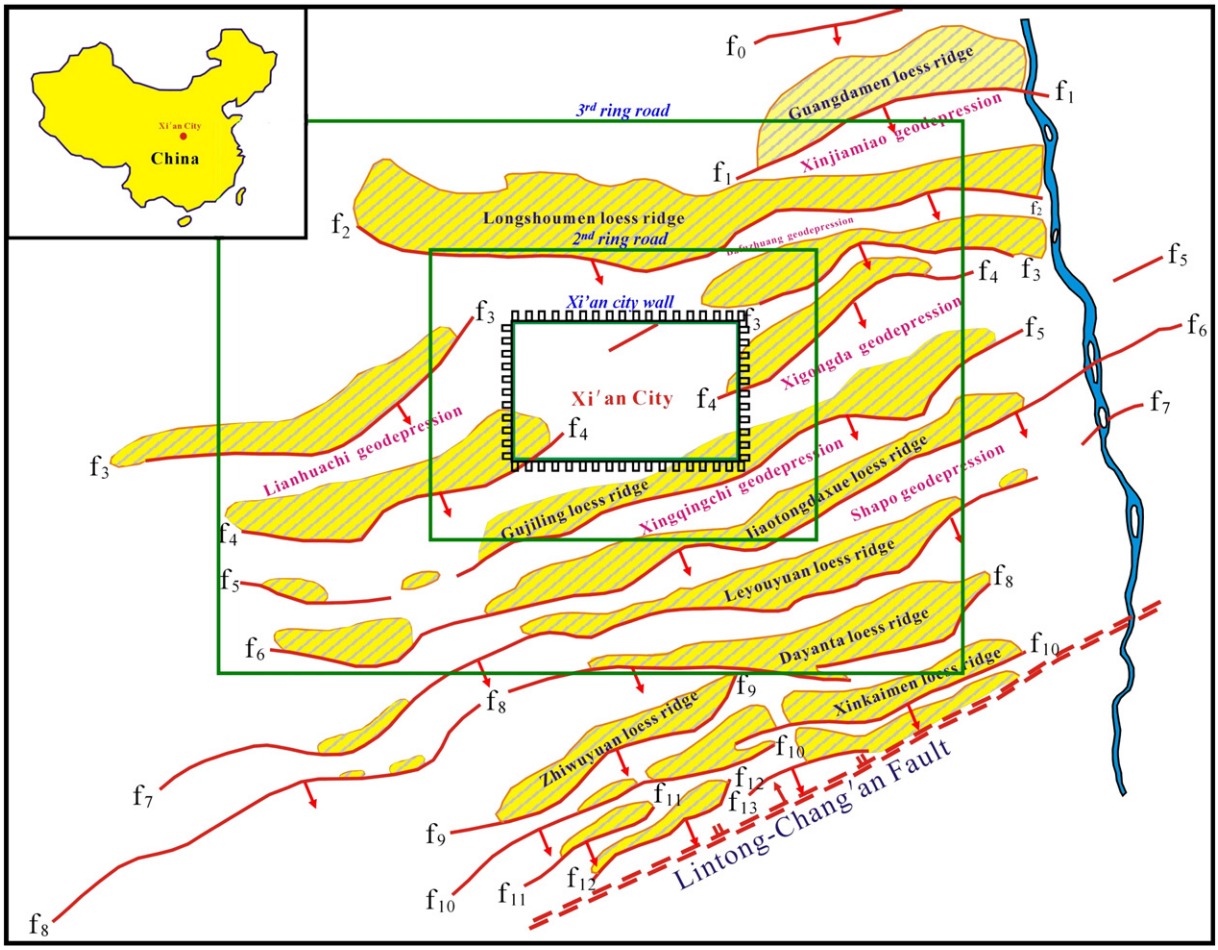

Fig. 1. Xi'an ground-fissure distribution map (Upper left panel indicates the map of the mainland China, the discovered ground fissures are labeled with f_i, $i = 1, 2, \ldots 13$).

settlement zones when the differential deformation is greater than the ultimate strain of the soil; (2) they are caused by the tectonic movement underneath, including the block tilting mechanism (Zhang, 1990), the gravity expanded mechanism (Zhao and Wang, 1995), etc. In the recent years, the second standpoint has been accepted by more and more researchers, who consider that ground fissures are expansions and extensions of tectonic shear fracture in soil layers near ground surface, and over-pumping speeds up their activities (Zhang, 1990; Peng et al., 1992, 2006; Lee et al., 1996).

For the second viewpoint, there are still some critical problems not solved yet, for example, whether the active faults are generally developed under Xi'an ground fissures. 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? Research shows that the development of ground fissure hazards is a progressively slow process, and there are differential settlements of soils on both sides of ground fissures. However, some questions still remain, such as, how the buried fissures spread to ground surface, and further, what plane and section characters do they have? How wide is the fissure's fracture belt, and are the deformation belt and the influence belt separate? All the above problems are related to the formation and expansion mechanism of ground fissures, and they are puzzling the researchers all the time.

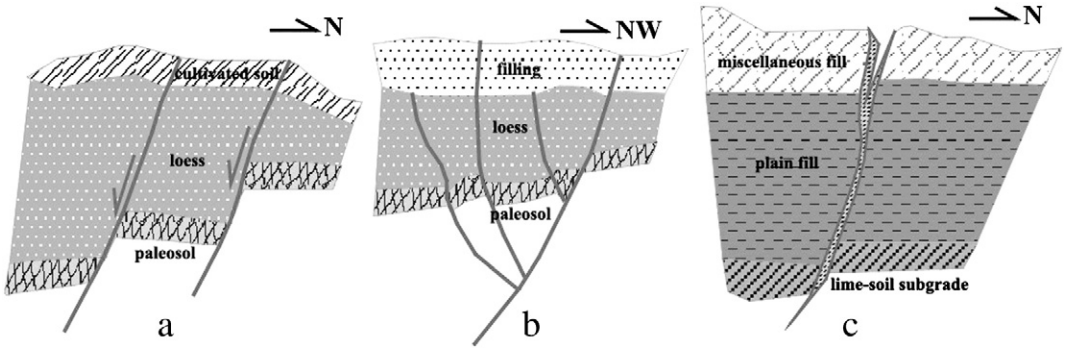

Fig. 2. Combined sectional patterns of Xi'an ground fissure (diagram a: step-shaped; diagram b: "y"-shaped and diagram c: tracing style).