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Ground-deformation Form and Control Factors Caused by Irrigation

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Abstract. Since irrigation in1968, ground deformation and geological disasters frequently happened. Based on depth investigation, survey and experimental research, this paper comprehensively analyze the geological environment background of Heifangtai. The distribution and types of ground deformation were systematically categorized. On this basis, this paper analyze control factors of ground deformation. Topography, geological structure, stratigraphy and lithology are the internal factors, while irrigation is the main predisposing factor. The ground deformation is the result of various factors. Study will provide the foundation for geological environment caused by irrigation. This paper has some theoretical and practical significance.

1. Introduction

Heifangtai is located between Yanguoxia and Bapanxia reservoir areas in Yongjing County, Gansu Province, about 70km west of Lanzhou City. Heifangtai is located at 103°16'-103°19' east longitude and 36°5'-38°7' north latitude. Heifangtai is composed of two terraces with different areas. The two compartments are opposite each other. The elevation is between 1710 and 1760m. It belongs to the fourth terrace of the Yellow River and is about 150m above the riverbed.

Since the large-scale irrigation of water in 1968, the area has subsided and geological disasters have occurred frequently. These disasters have caused huge losses to the country and people's lives and property, and triggered a research boom in the academic community on the disasters caused by irrigation in the Loess Plateau [1-6].

Since 2010, land collapse has occurred in many places in China, causing panic among the people. Geological workers are also doing in-depth research, and strive to find out its causes and mechanisms as soon as possible, which will usher in another craze for ground deformation research.

Although the locations of these disasters are far apart, the authors believe that their occurrence has something in common with the Heifangtai ground deformation, that is, human activities are their main predisposing factors. In view of this situation, this paper will systematically analyze the ground deformation of the Heifangtai, identify the type of deformation, and analyze the control factors in depth.

2. Geological background of Heifangtai

2.1. Topography

Heifangtai is the general name of Heitai and Fangtai. The landform type is loess platform, with obvious platform and gentle countertop. It is one of the largest four-level terraces in the Yellow River. The total area of the countertop is about 13.44km^2, which is 120-130m above the surface of the Yellow

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River. The surface is flat and the slope is about 5°. The slope of the inner side of the loess platform is 10-20°, and the slope of the outer side is generally 32-47°, and the local reach is 60°. Under the action of rainfall and agricultural irrigation, the slope of the slope has poor stability, and the slope erosion and gravity erosion are serious. There are more than 30 large and small gullies in the Heifangtai, of which the Hulang Gully is the longest and the depth is more than 100m. There are 87 sinking water holes and 31 landslides in the Heifangtai.

2.2. Geological Structure

The material composition of the Heifangtai includes the Cretaceous and Quaternary strata. The stratigraphic structure is simple and is now described in the bottom-up order as follows:

The Cretaceous Estuary Group (K1): the purple-red sandstone and mudstone interbedded layers have a monoclinic structure. The representative type is SE165~190° and the dip angle is 5~15°. Joints, cracks develop. The top surface depth of the rock formation is generally 1~2m, and the visible thickness is 60-80m.

Gravel of Pleistocene（Q_3）：Mainly composed of quartz sandstone, sandstone, granite, etc. The particle size is different, the roundness is good, the degree of cementation is low, and the thickness is 4~6m.

Alluvial Clay of Pleistocene（Q_3）: Fuchsia, with horizontal bedding, poor water permeability, thickness ranging from 12 to 12m.

Aeolian loess of Pleistocene(Q_3^{eol}): light yellow, structurally evacuated, with large gaps, vertical joint development, strong collapsibility, thickness 30~55m.

2.3. Meteorology and Hydrogeology

The annual average rainfall of the study area is 316.3mm, and the harvest year can reach more than 400 mm. The rainfall is concentrated, and the rainy season (June to August) accounts for 70%-80% of the annual rainfall. The annual average evaporation is 1689 mm, the evaporation is 5.3 times of rainfall, and the drought index is 3.5. It is a continental monsoon semi-arid climate.

Before the electric water pumping irrigation (before 1968), the groundwater in the study area was not developed, only distributed to Yehugou to Jiaojia Village, which was a bedrock fissure water with a small amount of water. According to relevant information, the total annual overflow is about $0.032\times10^4 m^3$; with the extension of irrigation time, the hydrogeology has changed significantly, and the overflow of spring water has gradually increased. According to the survey, by 1990, the number of springs increased to 63, and the total annual overflow reached $44\sim46\times10^4 m^3$, accounting for about 7.5% of the annual water withdrawal. The types of groundwater include bedrock crack water, gravel phreatic water and loess phreatic water. The groundwater quality is also close to the Yellow River water. The groundwater level is gradually increasing and the thickness of the aquifer is gradually increasing.

3. Ground Deformation Type and Distribution

Through the field investigation and research on the Heifangtai, the distribution and types of ground deformation are classified:

(1) Ground cracks. The ground fissures are distributed in the vicinity of cultivated land and wasteland around the trap group, and at the trailing edge of the landslide. The ground fissure is 5~30m long and 0.05~0.4m wide, which tends to collapse, the center of the landslide or the empty side of the slope. These rim cracks are not only a good channel for surface water infiltration, but also closely related to geological disasters such as landslides.

Based on the field investigation of the Heifangtai ground cracks, the authors refer to other research results to classify the ground fissures into the following three categories. The first type is a collapsible crack, which is mostly curved or linear. After the loess is wetted by surface water or groundwater, the loess is collapsible to form these ground cracks. The collapsing cracks mostly develop around the wet depression, and the scale is generally small. The second type is staggered fracture, which is mainly formed by gravity erosion. These ground fissures are mainly distributed at the back edge of the landslide. The vertical joints at the rear edge of the landslide are pulled and stretched by the front of the landslide to form ground fissures. This type of crack is generally parallel to the back edge of the landslide. The third type is tectonic fissure, which is formed by tectonic movement. The extension length and depth of tectonic fissure are large. Its essence can be seen as simple geological structure, not the main type of Heifangtai.

(2) Fissures, caves and collapses are the main parts of 50-100m away from the edge of the plateau. They occur in groups and zones, criss-crossing and non-uniform in plane distribution. Especially on the southeastern side of the plateau, it is widespread and densely distributed. These ground deformations develop along structural joints and fissures, mostly in long strips. There are four shapes in cross section, columnar, altar, dish and funnel, of which columnar is the most common.

(3) There are a large number of collapse caves and falling water caves in abandoned farming areas and nearby areas. These caves are honeycomb-shaped in plane, with diameters ranging from less than 1 meter to several meters. The water inlets and outlets are obvious and interconnected, forming "loess bridges" with different directions.

(4) Loess landslides: There are about 40 landslides in the study area, with different sizes and forming ages. It is the main geological hazard in Heifangtai. It can be divided into three major landslide groups: Jiaojiawan landslide group, with 18 landslides of different sizes; Huangziwan landslide group, with 9 single landslides and the landslide axis facing the Yellow River; Yanguojiwan landslide group, with 10 large landslides in this area. The main research object of this paper is ground subsidence, subsidence and so on. Landslide will be studied as a separate topic in the future. Here is only a brief description.

4. Analysis of Control Factors

Ground deformation refers to the collapse, settlement and cracking of some soils. It is a natural entity that exists objectively. The most direct influencing factors include topography and landform, stratigraphic lithology, geological structure, irrigation and hydrogeology.

4.1. Geomorphology

Due to the erosion of rivers and the gravity of high steep slopes, the landforms on the edge of the Heifangtai are mainly high steep slopes and accumulated landforms. The surface of Heifangtai is flat and wide, with an average slope below 5 ° . This geomorphological feature determines the form of cyclic transformation of surface water and controls the development opportunities of the characteristics of the loess. On the relatively flat plateau, the horizontal erosion of surface water weakens. Surface water converges in the depression or where vertical cracks develop, resulting in increased horizontal latent erosion. Surface disasters are dominated by collapse and crevices.

In the analysis of ground deformation in the study area, the rate of water supply (mainly irrigation) to the soil surface tends to exceed the rate of infiltration and surface runoff as the surface slope and geometry change. If surface water encounters crevices, caves or loose zones, large amounts of surface water flow into caves and crevasses. The latent erosion of the lower layers has increased significantly, forming a unique landscape. The loess platform such as the Heifangtai, under the strong erosion of special forms of flowing water, formed a loess latent erosion landform.

4.2. Geological Structure

Heifangtai is structurally located in a faulted basin. There is a deep trench of WE in front of the mountain, which splits the continuity of the accumulated loess. From the analysis of structure and strata occurrence, it is the product of fault activity. Quaternary neotectonic activity was active, accompanied by uplift and subsidence movement, resulting in some structural joints and a large number of cleavages, which provided a good channel for surface water infiltration and movement. It is one of the important factors affecting the generation and expansion of ground subsidence cracks.

At the bottom of loess deposits, small folded sedimentary structures are formed in low-lying areas due to the different topographic fluctuations of river beds. Although the occurrence of bedrock changes little, it can control the direction of groundwater movement. It intensifies the generation of underground passage and the change of subsidence from shallow to deep, from small to large. In addition, the seismic intensity in this area is between magnitude 6 and 7, and secondary earthquakes caused by reservoirs have a greater impact on the generation of Loess fissures.

4.3. Stratum Lithology

The stratum of Heifangtai is relatively simple, and the loess stratum plays a controlling role in the ground deformation.

The grain size composition of loess is as follows. According to the grain size analysis of loess in Heifangtai, the sand content, silt content and clay content of loess account for 31%, 46% and 23% respectively in the depth of 0-3 m. Sand grains account for 45%, powder grains 34% and clay grains 21% in the depth of 3-25 m. It can be seen that the characteristics of Heifangtai loess are sand.

The loess structure is analyzed as follows. Generally speaking, the Loess texture of Heifangtai is more uniform.Loess structure is relatively loose with porosity of 45.4-48.4%. Malan loess has a high content of sand grains and rich in calcium carbonate. Vertical joints of loess develop without horizontal bedding.

According to the measurements, the average horizontal permeability coefficient of the Loess in Heifangtai wasteland is about 3.618 × 10^{-4}cm/s. The average vertical permeability coefficient Kv is about 4.830×10^{-4}cm/s. With the increase of soil depth, the permeability coefficient of soil decreases gradually. The relationship between effective permeability coefficient and soil depth is as follows:

$$H=19.95-2.63K \quad (1)$$

$$K=\sqrt{K_v^2+K_h^2} \quad (2)$$

In the formula: H-soil depth (m);

K-soil effective permeability coefficient (10^{-4}cm/s).

With the increase of soil physical depth, the ratio of vertical permeability coefficient to horizontal permeability coefficient decreases gradually. At the depth of 10-20 m, the ratio of vertical permeability coefficient to horizontal permeability coefficient is less than 1, and the statistical relationship between Kv/Kh and depth H is as follows:

$$H=13.96-2.46Kv/K_h \quad (3)$$

Let Kv/Kh = 1, Ht = 11.50m can be obtained.

Obviously, the horizontal infiltration is close to the vertical infiltration in the depth of about 11.50 M. The saturation of loess in the depth of 19 m is close to 100%. The permeability coefficient of Q2 under Q3 is very small and can be regarded as a relative water-resisting layer, which causes the infiltration and leakage of irrigation water to erode in the shallow Malan loess and discharge from the top of Lishi loess. Because of the high erodibility and horizontal permeability coefficient of Heifangtai loess, the horizontal potential erosion of surface water after infiltration is greater.

4.4. Irrigation

Irrigation is the direct cause of surface deformation of Heifangtai. The change of irrigation method and irrigation quota also affects the evolution of surface deformation speed and form. Irrigation has greatly changed the physical and mechanical properties of loess. With the passage of irrigation time, these changes also directly or indirectly affect the ground deformation.

The area of Heifangtai Irrigation Area is 13.44 km^2, the average annual irrigation amount is 7×10^6 m^3, the annual output of 63 springs is 0.47×10^6 m^3, and the annual precipitation is 316 mm. As the groundwater level has exceeded the critical evaporation depth of loess, the actual evaporation amount is 0. Based on the equation of water balance in the closed zone, the water quantity (within one year) in the loess is 8.65 x 10^6 m^3, and then the annual average rising speed of the groundwater level is calculated. Since the groundwater level has exceeded the critical evaporation depth of loess, the actual evaporation is 0. Based on the equation of water balance in the closed zone, the amount of water retained in loess (within one year) is 8.65 ×10^6 m^3, and then the annual average rising speed of groundwater level is calculated.

It is calculated that the groundwater level of Heifangtai rises at a rate of 0.64 m annually and the saturated loess layer becomes thicker year by year. Of course, this is only a theoretical rise rate of groundwater level. According to the measured data, the rise rate of groundwater level at Heifangtai is less than this value. However, it is an indisputable fact that the saturated loess layer is getting thicker year by year because of the increase of groundwater level caused by irrigation.

Due to intense irrigation for many years, the physical, mechanical and hydraulic properties of Heifangtai soil have changed greatly, especially the permeability coefficient has decreased, resulting in the change of the interaction between irrigation water and sandy loess in the lower layer, and the surface deformation has gradually changed to the main form of latent erosion subsidence joints.

4.5. Groundwater

Groundwater in Heifangtai is mainly formed by the transformation of surface water such as irrigation water after infiltration, and is discharged in the form of spring water. Its impact can be summarized as follows:

(1) Groundwater in Heifangtai rises synchronously with irrigation amount, which promotes the formation of underground caverns. The properties of loess near the depth of 19 m have changed obviously, and its saturation is 100%. The permeability coefficient affects about 11.5m depth. At the same time, the strength of loess decreases greatly, which aggravates the speed of latent erosion and causes the loess to fall out before collapse.

(2) The movement of groundwater leached the soluble salt in the soil, and the salt content in the soil became lower. When the salt in the loess dissolves, the particles are dispersed and the water is taken away. It causes the change of loess structure and the further increase of porosity, which aggravates the latent erosion deformation.

5 . Conclusion

(1) The types and distribution of surface deformation of the black square platform are summarized in detail. According to the field investigation, the Heifangtai fracture is divided into collapsible fracture, staggered fracture and structural fracture.

(2) Landform, stratigraphic lithology, geological structure, irrigation and hydrogeology are the main controlling factors of surface deformation of Heifangtai. Topography, geomorphology, geological structure and stratigraphic lithology are the intrinsic factors of surface deformation of Heifangtai .

(3) Irrigation is the main inducing factor for the ground deformation of Heifangtai . The groundwater level of Heifangtai rises at a rate of 0.64 m every year, and the saturated loess layer is thicker year by year, which makes the properties of Heifangtai loess change greatly.

(4) The occurrence conditions, migration and drainage ways of groundwater in Heifangtai have promoted the use of ground deformation.

The surface deformation of Heifangtai is the result of comprehensive action of various factors. The mechanism of action is mainly latent erosion. To solve the current problems, we must start from solving the irrigation mode, carry out rational overall planning, and take biological measures, agricultural measures and engineering measures into account.

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