Development Characteristics and Stability Evaluation of Unstable Slopes in Huachi County

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Abstract. This paper divides the unstable slopes in Huachi County into soil and rock. The final deformation evolution of unstable slopes is landslide, collapse and continuous cumulative deformation to maintain an unstable state, in which landslides and collapse disasters may dominate. The typical Donggou unstable slope profile in the county is selected for analysis. The calculation results and numerical simulations show that the slope is stable under the conditions of self-weight and earthquake; The sections of the slopes 1-1′ and 3-3′ are basically stable under heavy rainfall conditions. The calculation results are basically consistent with the qualitative analysis, indicating that heavy rainfall is the main cause of unstable slope deformation.

1. Introduction
Huachi county is located in the eastern part of Gansu Province and deep in the hinterland of the Loess Plateau. The number of geological disasters in the territory is large and widely distributed, and the unstable slope is one of the main types of geological disasters in the investigation area [1-4]. The unreasonable construction of the county town has aggravated frequent geological disasters and has become an important factor affecting social and economic development and stability. Therefore, the stability analysis of the unstable slope is becoming more and more urgent, the unstable slope of Donggou is typical representative and has a great threat in Huachi. The author focuses on the analysis of the genesis and characteristics of the Donggou unstable slopes and evaluates its stability. The development of this work is of great significance in disaster prevention and economic development in Huachi county.

2. Formation lithology
The main strata lithology revealed in the exploration area is as follows [5-7].

The Huanhe-Huachi formation of the Zhidan Group in Cretaceous (K1h): Sandstone and mudstone interbed. The sandstone is purple-brown, granular texture and bedded structure; the mudstone is blue-gray, pelitic texture and bedded structure. The bedrock interbeds attitude are between 165°∠4°~310° ∠11°, the upper part is strongly weathered, the rock layer has a small dip angle and is partially horizontal. According to the regional geological data, the base rock layer has a large thickness and a maximum thickness of 800 m.
Middle and upper Pleistocene Series (Q3): Loess is widely distributed on the surface of the hilly-gully area. The thickness of Malan loess is 15-30m, it is light yellow, the texture is uniform, the consolidation is loose, macropore, vertical joints development, there are wormholes and plant root holes and small number of scattered calcium tuberculosis. Lishi loess is exposed in the upstream of the branch ditch, thick 40-180m, thickest up to 200m, yellow-brown, loose-slightly dense, slightly wet, uniform in soil, macropore development, vertical joints, paleo-soil layer visible in some places, rich in calcium tuberculosis.

Holocene Series (Q4): The alluvial deposit come from debris flow deposits in the channel and landslides and collapse deposits on both sides of the channel. The gravel layer below contains a small amount of cohesive soil, poor consolidation, the gravel sorting and roundness are poor, the particle size is 2~10cm, the maximum particle size is 30cm, and the thickness is 2~5m. The upper part is loess-like soil and silty clay, the structure is loose and the thickness is about 2~4m.

3. Unstable slope development characteristics

3.1. Unstable slope classification

There are 48 unstable slopes in Huachi County (Table 1), which are mainly distributed in areas with large thickness of loess. Divided into soil and rock unstable slopes by material composition. According to the final deformation evolution mode of unstable slope, it is divided into landslide, collapse and continuous cumulative deformation to maintain the unstable state, which may become the dominant state of landslide and collapse disaster, and only one of the continuous accumulated deformation maintains the unstable state. Divided into human engineering activities and natural causes by dominant trigger factors, They accounted for 77.1% and 22.9% respectively.

| Partitioning standards | Different developing types | Quantity | occupies compared |
|-------------------------|---------------------------|----------|-------------------|
| Material composition    | soil slopes               | 46       | 95.8              |
|                         | Rock slopes               | 2        | 4.2               |
|                         | Collapsse                 | 21       | 43.8              |
| Deformation model       | Landslide                 | 26       | 54.2              |
|                         | Continuous cumulative deformation maintains an unstable state | 1 | 2.0 |
| Trigger factor          | human activity            | 37       | 77.1              |
|                         | natural causes            | 11       | 22.9              |
|                         | well stability            | 0        | 0                 |
| Stability               | poor stability            | 32       | 66.7              |
|                         | bad stability             | 16       | 33.3              |

3.2. Development scale and development trend of unstable slopes

The unstable slopes widely distributed in the Huachi are all loess slopes, and structural types are nearly horizontally layered. Its length is 10-150m, width is 20-300m, thickness is 1-37m, slope is 32-80°, volume is 0.02×10^4~22.5×10^4m. The shape of the unstable slope is mainly convex, the potential damage is generally small, the induced factors are clear, and the macroscopic precursor is relatively obvious. The development trend of unstable slopes in Huachi county is divided into two types: one is instability after slope deformation and failure, which leads to collapse or landslide; the other is continuous deformation, but does not destroy and maintain an unstable state for a long time.

1) Slope instability evolves into a collapse or landslide

The cracks in the unstable slope continue to expand into cracks, and the unloading cracks develop along the slope, and the cracks have been generated at the trailing edge of the slope. These structural planes continue to expand-connect-through, and the overall stability of the slope is broken to cause...
instability, which generally manifests as collapse or landslide. The investigation found that the final possible lose stability of 26 unstable slopes was landslide, and 21 of the ultimate possible way of destruction was collapse.

(2) Continuous cumulative deformation maintains an unstable state
Most of the slopes in Huachi County have been tested for a long time, and they are in dynamic balance. When there is no external factor to accelerate the deformation, the deformation of the slope itself gradually accumulates and is temporarily stable. That is to say the slope is in a process of quantitative change, Only when it develops to qualitative change will it be unstable and destroyed.

4. Donggou unstable slope

4.1. Basic characteristics
The landform type of the Donggou unstable slope belongs to the water erosion loess hilly. The overall terrain is high in the east and low in the west. Gully development, topographical fragmentation, the strong transformation of humans has led to steep slopes. The unstable slope has an east-west width of 274m, the highest point elevation is 1484m, the lowest point elevation is 1277m, the relative height difference is 207m. The overall slope direction is 345°, the slope height difference is 3~24m, and the slope is 40~73°, and the slope of the local section is nearly erect. Malan loess and Lishi loess form the Donggou slope, which the Malan loess covers most of the slope and only the bedrock is exposed in the west slope. The drilling data shows that the upper part of the slope is thicker and the lower part is thime. There is a loess gully developed in the east of the slope (Figure 1), long-term water erosion leads to local collapse of the slope at the trailing edge of the gully, Loose matter is accumulated in the gully, and debris flows deposit at the foot of the gully. The shape is plateau or gentle slope at the top of the slope body. Due to the serious excavation of the slope foot by artificial mountain cutting, the middle part of the slope develops into a loess collapse (Figure 2), The collapse body is 22m high and 20m wide, The slope is steep and the slope is nearly upright, forming a large free surface.

4.2. Influencing factors of unstable slope in Donggou
(1) Terrain Effect. Most of the unstable slopes are artificially modified soil slopes, slope is 45-75° and some close to 90°. The overall terrain of the slope is steeper than the natural slope, and it has the conditions of the landslide and collapse.

(2) Rock type. The unstable slope formation is mainly composed of Malan loess, silt and silty clay make up loess, which has collapsibility and vertical joints development, it is easy to soften and quickly decrease in strength when it meets water, especially under the action of heavy rainfall, deformation is easy to occur.
(3) Artificial activity. A large number of houses and roads are built on the slope, which increases the height and slope and reduces the stability of the slope. At the same time, rainwater and domestic are discharged at random along the slope. Some water pipes have been in disrepair for a long time, rupture and leakage, water infiltration, and softening of the slope.

(4) Precipitation. Heavy rainfall is the main external factor for the deformation and destruction of slopes. The rain penetrates and washes the slope, causing the soil to soften and landslides and collapses.

Overall, Special conditions of the loess layer, artificial excavation to form high and steep slopes, a large number of cracks and collapses under the action of heavy rain, and the influence of rainfall is an important factor for the instability of unstable slopes.

4.3. Stability evaluation analysis

Through the exploration of the slope engineering area and the discrimination characteristics of the slope stability, there are three local collapses, slips, and the leading edge has a good free face in Donggou unstable slope. From the comprehensive judgment of external forces and earthquakes such as atmospheric precipitation, the stability of the slope is poor, It is possible to deform and destroy. Future damage will occur in the form of landslides and collapses.

4.3.1. Working condition calculation and Parameter selection. The stability calculation is calculated by three typical sections. According to the influencing factors and surrounding environment, and the engineering activities that may occur in the future of the collapse zone, the three working conditions of self-weight, self-weight + precipitation condition, self-weight + earthquake are selected for calculation. According to the “Code for Seismic Design of Buildings” (GB50011-2001), the seismic fortification intensity is VIII degrees, and the basic seismic acceleration value is 0.15g. According to the soil sample test data and soil structure characteristics, the original slope body is mainly composed of silt and silty clay, and the extreme value is removed. The average natural bulk density is 14.0KN/m³, soil void ratio is 1.066 and the natural specific gravity is 2.7. Calculate the saturated weight of the soil according to the following formula is 18.23KN/m³.

\[ \rho = \frac{G + e \rho_w}{1 + e} \]

Calculation formula: \( \gamma \)-saturated unit weight (KN/m³), \( \rho \)-saturation density (g/cm³), G-natural specific gravity of soil, e-void ratio, \( \rho_w \)-water density (1g/cm³).

| Table 2. Recommended physical and mechanical parameters |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Working Condition Parameter | Working condition 1 | Natural state | Working condition 2 | Saturated state |
|----------------------|---------------------|----------------|---------------------|----------------|
| Severe (KN/m³) | Effective cohesion C(KPa) | Effective angle of internal friction \( \phi \) (°) | Severe (KN/m³) | Effective cohesion C( KPa ) | Effective angle of internal friction \( \phi \) (°) |
| Malan loess | 14.0 | 22 | 25 | 18.23 | 20 | 22 |
| Lishi Loess | 18.7 | 22 | 35 | 21.1 | 20 | 32 |

Analysis and statistics of soil sampling test results shows that the internal friction angle is between 18～26° and the cohesion is between 12～36KPa. Soil parameters take the peak strength of loess which according to the test value, engineering experience value and soil parameters value in the project area. Select the soil internal friction angle value is 22° and cohesion is 25kPa; Due to the
formation of cracks in the slope, the water body infiltrates after rainfall, causing the mechanical parameters of the weak structural surface to continue to decrease. Therefore, the structural surface cohesive force $C$ is 22kPa and internal friction angle $\phi$ is 20° after rainfall (Table 2).

4.3.2. Determine calculation methods and results analysis. Calculate the easy to slide structural surface with Lizheng software and stability calculation of the loess slope. Sweden slice method is as follows.

$$ K_f = \frac{\sum (W_i \cos \alpha_i \tan \phi_i + C_i L_i)}{\sum (W_i \sin \alpha_i)} $$

Considering the rainfall conditions in Huachi county, the penetration of water into the slope body through the crack will create osmotic pressure on the structural surface. The calculation formula is

$$ K_f = \frac{\sum ((W_i \cos \alpha_i - R_{Di}) \tan \phi_i + C_i L_i)}{\sum (W_i \sin \alpha_i + T_{Di})} $$

Parallel slip surface force generated by osmotic pressure

$$ R_{Di} = r_w h_w L_i \sin \beta_i \sin(\alpha_i - \beta_i) $$

Vertical slip surface force generated by osmotic pressure

$$ T_{Di} = r_w h_w L_i \sin \beta_i \cos(\alpha_i - \beta_i) $$

The effect of earthquake action on slope stability

$$ K_f = \frac{\sum ((W_i \cos \alpha_i - A_i \sin \alpha_i) \tan \phi_i + C_i L_i)}{\sum (W_i \sin \alpha_i + A_i \cos \alpha_i)} $$

Calculation formula: $\alpha$ -Nth block slip surface inclination(°); $\beta$ - Nth block groundwater flow direction (°); $W_i$ - Weight of the i-th block(kN/m); $C_i$-Cohesion of the i-th block (kPa); $\phi_i$-Internal friction angle of the i-th block (°); $L_i$-Length of the i-th block slip surface(m); $A_i$-Earthquake force of the i-th block (kN/m); $A_i = a_i \times W_i$; $K_f$-stability coefficient.

The stability calculation diagram is shown in Figure 3, Figure 4, and Figure 5, and the calculation results are shown in Table 3.
Table 3. Stability coefficient calculation result table

| Working condition     | Self-weight | Self-weight + precipitation | Self weight + earthquake |
|-----------------------|-------------|-----------------------------|--------------------------|
| Donggou unstable slope 1-1'/ | 1.22        | 1.14                        | 1.17                     |
| Donggou unstable slope 3-3'/ | 1.18        | 1.09                        | 1.16                     |
| Donggou unstable slope 4-4'/ | 1.25        | 1.16                        | 1.20                     |

The stability evaluation standard is based on the "Landslide Prevention Engineering Exploration Specification", the steady state of each slope is divided according to the following criteria.

| Fs<1.0     | Unstable          |
| 1.0≤Fs<1.05 | Not stable        |
| 1.05≤Fs<1.15 | Basically stable |
| Fs≥1.15    | Stable            |

Quantitative calculation of slope stability, slopes are stable under self-weight and seismic conditions; Slopes section 1-1', 3-3' are basically stable under heavy rainfall conditions, which results are basically consistent with the deformation signs and qualitative analysis of unstable slopes, it also shows that heavy rainfall is the main reason of unstable slope deformation.

4.3.3. Stability numerical simulation. Two typical sections were chosen for stability calculations. Selecting self-weight and self-weight + precipitation of two conditions for numerical simulation (Figure 6, Figure 7), which according to the factors affecting the deformation, surrounding environment and possible future engineering activities of the slope area.
The numerical simulation results show: under the current condition, the Landslide safety factor is 1.555, and the slope is in a stable state; under the heavy rainfall conditions, the Landslide safety factor is 1.055, and the slope is in a basically stable state.

5. Conclusion

1. The unstable slopes in Huachi county are dominated by soil slopes with few rock slopes. The final deformation evolution of unstable slopes is landslide, collapse and continuous cumulative deformation to maintain an unstable state, in which landslides and collapse disasters may dominate. The development trend of unstable slopes is that the slopes lose their stability after deformation and collapse, resulting in collapse or landslide.

2. Special loess conditions, artificial excavation to form high and steep slopes, a large number of cracks and collapses under the action of heavy rain are important factors affecting the instability of unstable slopes in Huachi county.

3. Computational Simulation shows that the Donggou unstable slopes are stable under the conditions of self-weight and earthquake; The sections of the slopes 1-1 and 3-3 are basically stable under heavy rainfall conditions. The calculation results are basically consistent with the qualitative analysis, indicating that heavy rainfall is the main cause of unstable slope deformation.

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