Prediction of Landslide Hazards and Geological Disaster Prevention Measures for the Hengling Yao Township Landslide Cluster in Dao County

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Abstract: In recent years, frequent geological disasters triggered by heavy rainfall have posed significant threats to the safety of people's lives and property. Taking the Hengling Yao Township landslide cluster as an example, this paper combines survey results and experimental data to predict the hazards of the landslide cluster to surrounding residents by calculating the sliding distance of the DX0033 landslide and proposes reasonable and feasible prevention measures.

Keywords: Geological Disaster Prevention and Control; Sliding Distance; Dao County

1. Engineering Overview

Dao County, under the jurisdiction of Yongzhou City, Hunan Province, is located in southern Hunan and the central part of Yongzhou. It lies at the transitional zone between China's second and third topographic steps, where the Nanling Mountains transition to the Dongting Lake Plain. The terrain is highly variable, and geological disasters occur frequently.

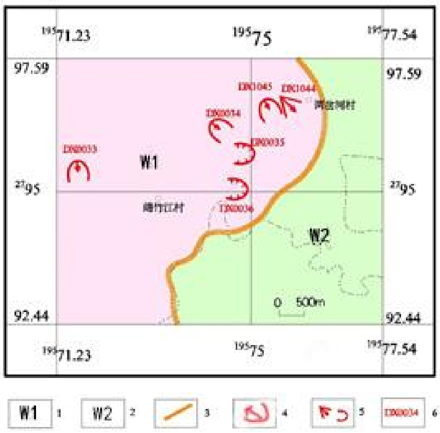

Figure 1. Schematic Diagram of Geological Disaster-Prone Sections Along the Daoheng Highway in Hengling Yao Ethnic Township.
1—High-risk geological disaster zones and numbering; 2—Low-risk geological disaster zones and numbering; 3—Hazard classification boundaries; 4—Landslide; 5—Unstable slopes and collapses; 6—Field numbering.

The Hengling Yao Township landslide cluster is located along the Hengling-Daoheng Highway in an eroded and denuded high hilly area. It has experienced multiple geological disasters, with the largest being the DX0033 rock landslide in Mianzhujiang Village (Group 2). This area includes 3 landslides, 2 unstable slopes, and 1 collapse. Topographically, all six disaster points are situated in valleys with large relative elevation differences and steep slopes. From a lithological perspective, the disasters developed in the Lower Cambrian Series ($\in_1$) lightly metamorphosed quartz sandstone interbedded with slate and the Middle Cambrian Lower Group ($\in_1^2$) metamorphosed quartz sandstone. The slopes are densely populated, transportation is limited (only the Daoheng Highway connects to the outside), and the terrain is highly rugged.

2. Landslide Cluster Hazard Prediction

The DX0033 landslide, the most severe in the Hengling Yao Township landslide cluster, is analyzed to assess its hazards. Dao County has a subtropical humid monsoon climate with mild winters and summers. According to Li Xiang et al.[1], as comprehensive rainfall and duration increase, the frequency of disaster-inducing rainfall events rises rapidly. Therefore, under heavy rainfall, the Hengling landslide cluster is highly prone to sliding. Field measurements indicate annual deformation of the landslide cluster during flood seasons. Although partial treatments (e.g., debris removal and slope toe backfilling) have been implemented, funding constraints prevent comprehensive remediation.

Field surveys reveal steep, unstable slopes with residential buildings, roads, and farmland. Existing damage includes 30 destroyed houses, 156 meters of damaged roads, direct economic losses of ¥1.635 million, approximately 27 hectares of farmland, and 795 meters of at-risk roads endangering pedestrians and vehicles.

Per the *Geological Disaster Risk Assessment Standards (DZ/T 0286-2015)*, the six disaster points (3 landslides, 2 unstable slopes, 1 collapse) are classified as medium hazard severity, high developmental intensity, and high-risk levels.

3. Landslide Cluster Hazard Analysis

3.1 Analysis of Adverse Factors

The Hengling landslide cluster has a dual-layered structure: upper lightly metamorphosed quartz sandstone interbedded with slate (highly weathered, loose, moist) and lower metamorphosed quartz sandstone (hard to very hard slate interbedded with lightly metamorphosed sandstone). Under unfavorable conditions, the slope will continue to deform and eventually collapse. Key adverse factors include:

3.1.1 Topography and Geomorphology. According to Gao Zhihui[2], slope stability decreases sharply when gradients range from 35° to 55°. The landslide cluster is concentrated in eroded high hilly gullies or mountain edges, with slopes 40–70 meters high and gradients of 30°–60°. Steep slopes and favorable free-face conditions create gravitational sliding forces conducive to disasters.

3.1.2 Lithology of Overlying Strata. The upper layers of weathered quartz sandstone and slate are structurally loose and mechanically weak. Rainfall infiltrates weak structural planes, forming sliding zones that trigger landslides.

3.1.3 Rainfall Impact. Prolonged heavy rainfall reduces shear strength, increases soil weight, and dissolves minerals, accelerating slope failure.

3.1.4 Severe Soil Erosion. Intensive farming in densely populated areas exacerbates soil erosion, disrupting slope geometry and equilibrium.

3.1.5 Groundwater Influence. Long-term groundwater dissolution reduces cohesion and internal friction angles, forms voids, and facilitates surface water infiltration, further weakening slopes.

3.2 Landslide Hazard Prediction

3.2.1 Calculation of Landslide Sliding Distance. Taking the DX0033 landslide as an example, the sliding distance is calculated to delineate hazard zones and guide evacuation efforts.

The sliding distance can be calculated using multiple methods. For DX0033, Equation (1) is recommended, incorporating mechanical parameters:

$$L_{MAX} = n * \frac{\Delta H}{0.5 * tan\varphi} \quad (1)$$

Where:

L max: Maximum horizontal sliding distance of the landslide mass (m);

ΔH: Elevation difference between the front and rear edges of the landslide mass (m);

n: Sliding condition coefficient of the landslide mass (refer to Table 1);

ϕ: Comprehensive internal friction angle (°).

Table 1. Sliding Condition Coefficient Table for Landslide Mass

Sliding Condition	Coefficient (n)
The shear outlet is located at the front edge of the mass, with narrow and restricted accumulation area topography, significant barriers ahead, and poor free-face conditions.	0.1–0.3
The shear outlet is located in the toe area, with undulating accumulation area topography, distributed barriers of varying scales, and moderate free-face openness.	0.3–0.5
The shear outlet is near the toe, with slightly undulating accumulation area surface, no large barriers, and relatively good free-face conditions.	0.5–0.7
The shear outlet is in a high free-face zone, with flat and open accumulation area ahead, no barriers, and fully exposed free-face.	0.7–0.9
The shear outlet has significant free-face height, with gently extending terrain ahead and completely lacking barriers, offering extremely superior free-face conditions.	0.9–1.0

Based on the topographic features and barrier distribution of the DX0033 landslide, the assigned sliding condition coefficients and calculation results are listed in Table 2.

Table 2. Sliding Distance Calculation Results for DX0033 Landslide

Name	Sliding Condition Coefficient (n)	ΔH (m)	ϕ(°)	Lmax (m)
DX0033 Landslide	0.2	20	23	19

3.2.2 Prediction of Landslide Group Hazards.From the calculation results in Table 2, it can be seen that once the DX0033 landslide occurs, it will generate a significant sliding distance, with a maximum sliding distance exceeding 20 meters. This directly threatens the property and safety of 16 households (over 80 people) nearby. In terms of the coverage range of sliding distance, a landslide would involve 3,400,000 m^3 of material. This geological disaster poses threats to numerous targets over a wide area, highlighting prominent social issues. Strict prevention and early treatment are imperative.

4. Goals and Measures for Geological Disaster Prevention

4.1 Prevention Goals and Principles

4.1.1 Prevention Goals. The landslide group in Hengling Yao Ethnic Township has already destroyed 30 houses, damaged 156 meters of roads, caused direct economic losses of 1.635 million yuan, threatened 40 acres of farmland and 795 meters of roads, and endangered the safety of pedestrians. The coverage area is large, and the hazard risk is high. To enhance disaster prevention effectiveness, establishing reasonable and effective prevention goals is fundamental. The goals are to control the further development of existing disasters, prevent new disasters from emerging in the original areas, stabilize all disaster-prone regions, eliminate hidden geological hazards, and protect the lives and property of nearby residents.

4.1.2 Prevention Principles. Geological disaster prevention is a systematic project that requires both "prevention" and "treatment," integrating the two. For the Hengling Yao Ethnic Township landslide group, it is necessary to prevent new disasters while treating existing ones to halt their progression. Principles include adhering to practical conditions, following objective laws, coordinating planning, prioritizing key areas, implementing step-by-step measures, and advancing holistically. In summary, disaster prevention should adhere to the principle of "prevention first, combining avoidance and treatment" [4].

4.2 Prevention Measures

Based on survey results and prevention recommendations from relevant units, and considering the geological environment, the primary measures for the Hengling Yao Ethnic Township landslide group include anti-slide retaining structures, supplemented by surface drainage, vegetation-based bioengineering, and relocation of residents when necessary. Specific measures are as follows:

4.2.1 Drainage. Construct open ditches on slopes to intercept or divert surface water outside the sliding mass. The ditches shall be cast-in-place concrete. For slopes with abundant groundwater, install tubular blind drains to collect and drain groundwater within the sliding mass.

4.2.2 Slope Reduction and Unloading. For steep slopes, reduce the load by backfilling the slope toe or cutting the slope to lower its gradient.

4.2.3 Modification of Slope Rock and Soil Properties. Depending on local soil conditions and economic factors, adopt grouting, electrochemical stabilization, or other methods to enhance soil integrity. Combine with bioengineering and landscaping by planting vegetation to prevent surface water infiltration and improve slope stability.

4.2.4 Retaining Wall Method. If buildings or roads exist at the slope toe, construct retaining walls after slope reinforcement to prevent sliding rock and soil from threatening residents and pedestrians.

4.2.5 Relocation of High-Risk Areas. The DX0033 landslide, located in Group 2 of Mianzhu Jiang Village, Hengling Township, is classified as large-scale. It has destroyed 3 households (30 houses) and originally threatened 16 households (80 people). Residents began relocating in 2006, and all surrounding residents have now moved beyond 1 km from the landslide. Current threats are limited to economic crops on terraced slopes, requiring only simple treatment.

4.2.6 Enhanced Monitoring. Among the surveyed ground collapse areas, 10 are relatively stable and 6 are unstable. The scale and risk of karst-type ground collapses are small. Prior to detailed surveys, predicting their impact range is difficult, and relocation is impractical. It is recommended to strengthen monitoring while conducting investigations into karst development.

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