

GIS BASED SEISMIC STABILITY ZONATION OF SLOPE AROUND LANZHOU CITY

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Abstract: Using a pseudo-static analysis method of slope instability proposed by Koppula, combining with GIS technology, the slope stability during earthquake around Lanzhou City under three probability of exceedance (2%, 10% and 63.5% probability of exceedance in 50 years) is forecasted. And the slope stability zonation maps during earthquake are accomplished. The slopes been located south of Xigu and Qilihe Zone in Lanzhou have the highest landslide susceptibility and should be defended preferentially.

Key words: slope stability; pseudo-static method; GIS

1 Introduction

Landslides are one of the most damaging collateral hazards associated with earthquakes. In fact, damage from triggered landslides has sometimes exceeded damage directly related to strong shaking and fault rupture [Jibson *et al.*, 2000]. Therefore, many previous studies were related to the evaluation methods of landslide hazard. In general, there are mainly three types of evaluation model: deterministic model, statistical model and heuristic model. Deterministic model was often used in a large scale area and the hazard in absolute values in the form of safety factors, or the probability of failure could be provided [Jibson *et al.*, 2000; Luzi and Pergalani, 1996; Miles and Ho, 1999; Refice and Capolongo, 2002]. In statistical model, the combination of factors that have led to landslides in the past are determined using bivariate or multivariate statistical analysis, and then the result are used to predict future landslides [Clerici *et al.*, 2002; Dai and Lee, 2002; Donati and Turrini, 2002; Gupta and Joshi, 1990]. This model is suitable for medium scales. In heuristic model, the contribution of the factors to landslide is evaluated by the experts and then the landslide hazard is forecasted [Barredo *et al.*, 2000; Esmali and Ahmadi, 2003].

In this study, we used deterministic model to predict landslides of the slopes around Lanzhou city. A pseudo-static analysis method proposed by Koppula was chosen to analysis the stability of the slopes [Koppula, 1984]. Geophysical information system (GIS) database and spatial analysis techniques were used during the data integration and analysis process.

2 Method for calculating safety factor of slopes

Siyahi and Ansal developed a zoning method for slope instability by modifying a method proposed by Koppula [Technical Committee for Earthquake Geotechnical Engineering, 1999]. The method originally proposed was a pseudo-static evaluation of slope stability utilizing a seismic coefficient A to account for the earthquake induced horizontal forces [Koppula, 1984]. The variation in shear strength with depth is assumed linear and potential failure surface is taken as a circular arc. A linear variation with depth is assumed regarding the shear strength of normally consolidated soils. The safety factor, F_s , can be defined as:

$$F_s = \tan \phi \cdot N_1 \quad 1$$

where,
$$N_1 = \frac{3(\alpha + \cot \delta - \alpha \cot \alpha \cot \delta)}{\sin^2 \alpha \cdot \sin^2 \delta (D_1 + D_2)}$$

$$D_1 = 1 - 2 \cot^2 \beta - 3 \cot \alpha \cot \beta + 3 \cot \beta \cot \delta + 3 \cot \delta \cot \alpha - 6n \cot \beta - 6n^2 - 6n \cot \alpha + 6n \cot \delta$$

$$D_2 = A(\cot \beta + \cot^3 \delta + 3 \cot \alpha \cot^2 \delta - 3 \cot \alpha \cot \beta \cot \delta - 6n \cot \alpha \cot \delta)$$

where, α is the center angle, δ is the obliquity of the secant of circle arc, n is distance from the bottom of slope to the bottom of circle arc, β is the angle of slope and ϕ is the angle of shear strength.

Thus the safety factor depends on the angle of shear strength and stability number, N_1 representing the configuration of the slope and failure surface. The minimum values of the stability number are determined by carrying out a parametric study in terms of α , δ and n to find out the most critical failure surface.

3 Building GIS database

Lanzhou city is located in the area covered by big thickness loess. The three main type of the seismic hazard of loess are subsidence, liquefaction and landslide. Geographical map, micro zonation map of seismic acceleration, loess thickness map, geomorphologic map, ground water depth map, slope type map and geotechnical data were collected and digitalized to build GIS database. Subsidence and liquefaction prediction zonation has been described by Wang et al [2001]. The data related with landslide were mainly seismic acceleration, contour, slope distribution and geotechnical data.

Microzonation result of seismic acceleration [Sun and Chen, 1991] was shown in figure 1. The corresponding seismic acceleration of each zone under three probability of exceedance (2%, 10% and 63.5% probability of exceedance in 50 years) was summarized in table 1.

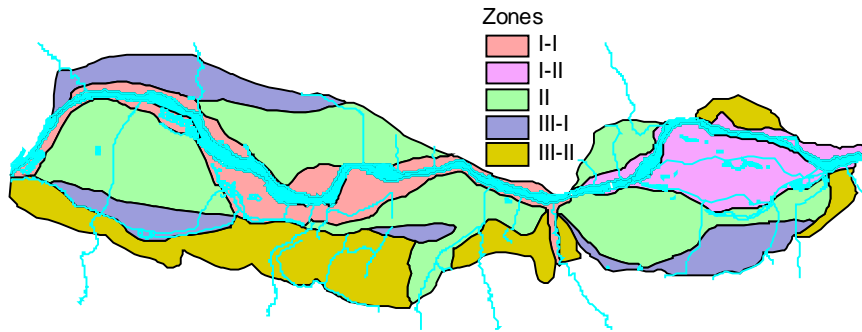


Figure 1. Microzonation map of seismic acceleration at Lanzhou city [Sun and Chen, 1991].

Table 1. Corresponding seismic acceleration of each zone under three probability of exceedance.

Zone	Seismic acceleration □ gal □			
	63.5%	10%	2%	
□	□-□	60	210	440
	□-□	70	220	450
□		75	240	450
□	□-□	80	240	440
	□-□	120	340	580

The main slope types around Lanzhou city are loess slope, loess and gravel slope, clay rock slope, grit rock slope, rock bits slope and un-integrity slope. The distribution of the slope types were plotted in figure 2. The corresponding shear strength angle vales were assigned to each slope type based on the geotechnical data.

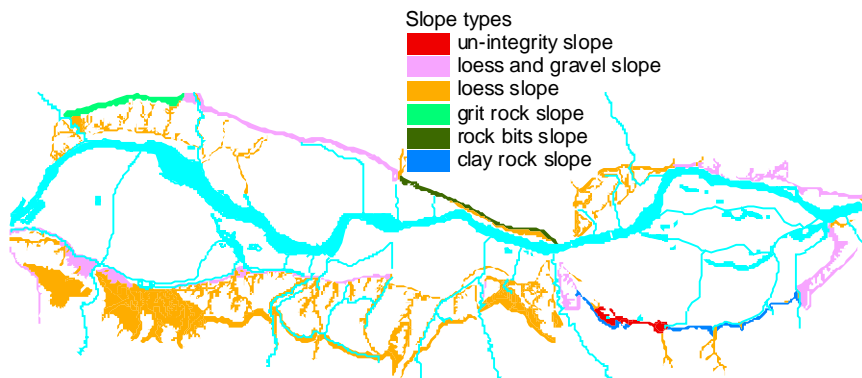


Figure 2. The distribution map of slope types around Lanzhou city.

The contour theme with altitude attribution was converted to TIN theme in ArcView with 3D analysis extension. Then the TIN theme was converted to grid theme which could generate slope angle theme using slope method in Avenue.

For to calculate the safety factor using Koppula method, we need to know the angle of shear strength ϕ , seismic coefficient A and slope angle β . The other parameters α , δ and n could be assigned values by scanning method. Using spatial analysis extension of ArcView, the grid theme of shear strength angle, seismic coefficient and slope angle were generated with 200m×200m cell size. Then formula 1 was used to calculate

the safety factor of each cell. This process was carried on by writing program with Avenue in ArcView.

The calculated factors of safety were considered in three groups with respect to risk levels as: high for $F_s < 1$, moderate for $1 \leq F_s \leq 1.5$ and low for $F_s > 1.5$.

4 Stability zonation results

Under 2% probability of exceedance in 50 years condition (figure 3), the slopes at south of Lanzhou and the slopes at north of Chengguan district have high risk level of instability. The slopes at north of Anning district have moderate risk level of instability. There are few slopes with low risk level for instability due to their small slope angle around Lanzhou city.

Under 10% probability of exceedance in 50 years condition (figure 4), the slopes with high risk level for instability mainly are located at south of Xigu district and Qilihe district. The slopes around Chengguan district have moderate risk level for instability. The slopes at north of Anning district have low risk level for instability.

Under 63.5% probability of exceedance in 50 years (figure 5), no slopes have high risk level for instability. The slopes with moderate risk level for instability are located scatteredly at south of Xigu district and Qilihe district with small area. Most slopes have low risk level for instability.

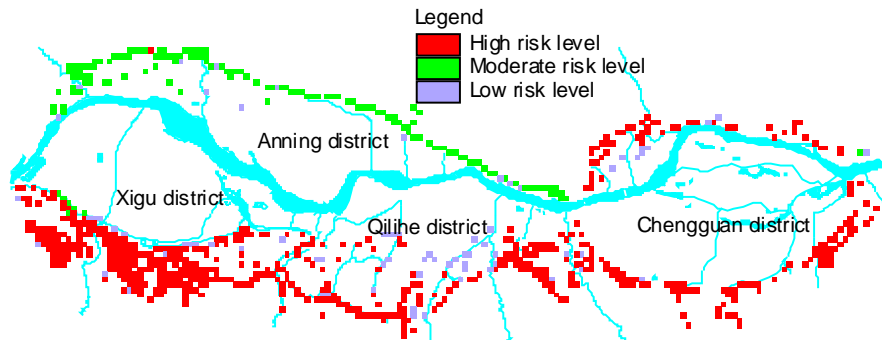


Figure 3. Seismic stability zonation map of slopes around Lanzhou city (2% probability of exceedance in 50 years)

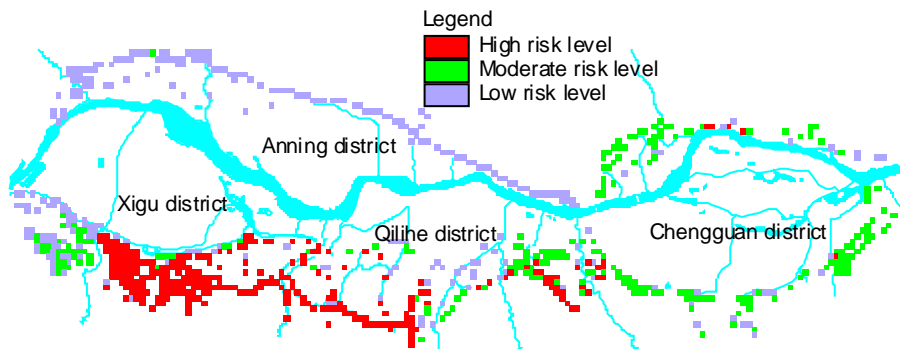


Figure 4. Seismic stability zonation map of slopes around Lanzhou city (10% probability of exceedance in 50 years)

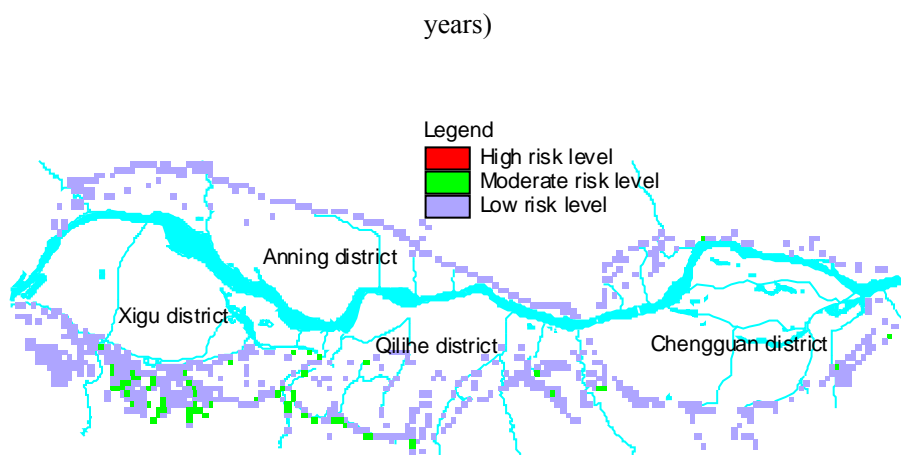


Figure 5. Seismic stability zonation map of slopes around Lanzhou city (63.5% probability of exceedance in 50 years)

From above results we can see the slopes at south of Xigu district and Qilihe district have the highest landslide susceptibility in Lanzhou city. Many landslides occurred in this region in history [Wu *et al.*, 1996], suggesting that the results are reasonable.

5 Conclusion

Based on the deterministic model for landslide evaluation, the distribution of safety factor of the slopes around Lanzhou city under three probability of exceedance were calculated using a pseudo-static analysis method of slope instability proposed by Koppula. GIS technology was used to support this work.

The results of seismic stability analysis of the slopes around Lanzhou city agree with the history landslide occurrence. The slopes at south of Xigu district and Qilihe district have the highest landslide susceptibility, which region should be defended preferentially.

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