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An integrated physical-based method for regional heterogeneous terrace slope stability analysis

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Influenced by the uplift of the Qinghai-Tibetan Plateau and fluvial downcutting, a series of fluvial terraces have been formed in the western part of the Chinese Loess Plateau, along the Yellow River and its tributaries. Under the influence of intensifying human activity, the slopes are becoming increasingly prone to landslides. However, none of the current methods of evaluating regional land stability have been applied to highly heterogeneous terrace slope areas. Consequently the stability of the slopes located on the terraces in the Lanzhou area of Gansu Province, which are several hundred meters high, has not been appropriately and quantitatively evaluated, and nor have the landslides been simulated under different triggering conditions. Here we present a comprehensive analysis of the impact of natural factors and human activity on the stability of terrace slopes. Our approach comprises the application of a 3D laser terrain scanner, 3D images of the subsurface, a geological survey, a laboratory study of soil mechanics, and other experiments. In addition, quantitative evaluation was conducted using computer analysis and simulation tools, in order to assess the stability of typical terrace slopes. Subsequently a physically-based stability model was established by using distributed GIS, and validated using PS-InSAR (Permanent Scatterer Synthetic Aperture Radar Interferometry) results. Our main findings are summarized as follows:
(1) 16 classes of terraces slope were selected based on the systematic classification method applied to typical loess terraces slopes. We took into account the mechanical factors of the overlying loess and alluvial formation, together with the sub-mechanical properties of silty clay sediments (secondary loess) of different ages, and also considered the structural properties of the underlying bedrock and the geomorphic features of the immediate area around the slopes.
(2) We summarize the shear resistance parameters of loess that was formed during different stages. For silty clay loess samples at all levels of the terrace, the unsaturated ring shear test was conducted under 8 different sets of moisture conditions.
(3) Examples of the computation of slope stability in an area based on heterogeneous slope elements and physical mechanisms are comparatively rare. Three limit equilibrium methods were used to calculate the 16 different typical slope stabilities under 8 different water content regimes, 10 different slopes and under a 0.2 g earthquake loading. The fitted regression equation indicates that the stability coefficient and slope water content are negatively correlated, with R2 close to or greater than 0.8.
(4) In a comparison of the verified PS-InSAR data, the existing landslide catalog and the FOS obtained using three different calculation methods, the three different limit equilibrium methods exhibit varying degrees of precision and accuracy. The Morgenstern-Price method achieved the highest accuracy rate of 75%. When addressing the issue of the stability calculation of terrace slopes with different water contents and different degrees of slope erosion, the three limit equilibrium methods yield good results and would have predicted the landslides at Shixiakou and Baoensi, in Lanzhou.

Keywords: heterogeneous terrace slope, landslide, stability analysis, PS-InSAR, Lanzhou