Sensitive Clay Slope

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Sensitive clays are known for producing retrogressive landslides, also called spread or flowslides. The key characteristics associated with the occurrence of these landslides on a sensitive clay slope must be assessed, and the potential retrogressive distance must be evaluated. Common risk analysis methods include empirical methods for estimating the distance of potential retrogression, analytical limit equilibrium methods, numerical modelling methods using the strength reduction technique, and the integration of a progressive failure mechanism into numerical methods. Methods developed for zoning purposes in Norway and Quebec provide conservative results in most cases, even if they don't cover the worst cases scenario. A flowslide can be partially analysed using analytical limit equilibrium methods and numerical methods having strength reduction factor tools. Numerical modelling of progressive failure mechanisms using numerical methods can define the critical parameters of spread-type landslides, such as critical unloading and the retrogression distance of the failure. Continuous improvements to the large-deformation numerical modeling approach allow its application to all types of sensitive clay landslides.

Keywords: sensitive clay ; stability analysis ; retrogressive distance

1. Introduction

Sensitive clays are known for producing retrogressive landslides, also called spread or flowslides. The key characteristics associated with the occurrence of these landslides on a sensitive clay slope must be assessed, and the potential retrogressive distance must be evaluated. Common risk analysis methods include empirical methods for estimating the distance of potential retrogression, analytical limit equilibrium methods, numerical modelling methods using the strength reduction technique, and the integration of a progressive failure mechanism into numerical methods.

2. Discussion

Risk analysis in sensitive clays slope is undertaken to prevent or minimize the risk of two principal landslide types: sensitive clay spread and sensitive clay flowslides. These two types of landslide develop from different mechanisms. Flowslides are a retrogressive sequence of circular slides and are more likely to occur in sensitive clays. Spreads result from the progressive formation of a single failure, and these failures can occur in less sensitive clays than required for flowslides [1]. Generally, it is difficult to predict the type of landslide that may be produced on a given slope. The type will depend highly on the composition of the slope, e.g., the presence (or not) of a stiff crust above the sensitive clay layer, and the triggering factor, e.g., the unloading at the toe and loading at the top [2]. This uncertainty underlines the importance of analysing each slope for both types of slide and triggering factors.

Methods have been developed for zoning purposes in Norway and Quebec, and these approaches provide conservative results in most cases [3]. Those are based on empirical factor developed to identify material susceptible to produce large retrogression. When a slope meets certain criteria, as a liquidity index (I_L) of at least 1.2 and a S_r smaller than 1 kPa for example, a limit of retrogressive distance is established for this given slope. Therefore, a hazard zone is delimited. For further analysis, stability can be assessed.

The limit equilibrium methods neglect some important aspects of sensitive clay slopes susceptible to progressive failure. The shear strength value obtained with these methods does not necessarily represent the actual values produced during a slide; it is more likely to be a value between peak strength and residual strength. The utilization of the peak strength rather than a more accurate value can greatly overestimate the safety factor. These results illustrate the limits of analytical approaches for evaluating progressive failure.

In the case of flowslides, using an analytical method or applying SRF to numerical methods can determine the initial rotational slip surface and its safety factor. However, in the case of a spread landslide, the limit equilibrium methods do not considerate the loss of strength after the initiating of the deformation and the horizontal propagation of the shear bands.

Wang and Hawlader [2] demonstrated how to model the effect of unloading at the toe of the slope on the propagation of shear bands. For this, they applied a large-deformation FE modelling technique.

The use of numerical modelling has been adapted to the progressive failure mechanism approach for the stability analysis of spreads. Numerical modelling has recently been used for the analysis of sensitive clay spreads by focusing on the behaviour of the propagating shear bands [2][4][5][6][7]. It then becomes possible to simulate a weak zone and its potential distance of propagation [8] or to simulate scenarios of triggering factors and their effects on failure initiation. Dey et al. [5] were among the first to model the conditions required to obtain horst and graben structures in sensitive clay slides. However, the safety factor is not mentioned in this study as the behaviour of the weak zone was the primary focus of interest.

3. Conclusions

The main objective of this paper is to provide a better understanding of the risk analysis of sensitive clay slopes. Our overview of the commonly applied methods makes it possible to develop some generalizations.

Empirical determinations of retrogression potential are used in the mapping of hazards. Such maps have been developed for specific areas in Norway and Quebec. All these methods have limitations, such as the necessity to have ancient scars near the study area for the MTMDET approach, the presence of flowslides in Norway that exceed the 1:15 ratio, and the lack of development of these methods for spreads. Nonetheless, empirical approaches remain in use in these countries. They also represented the first step to conduct in a landslide risk analysis study in sensitive clay slope.

Analytical methods for stability analysis can be used for calculating the safety factor of the possible initial slip in the case of flowslides. The simple use of SRF in numerical modelling can achieve the same result and identify the critical slip surface. Combined with the risk area zone delimited with empirical methods, it is possible to answer those two questions: Will it slide? How far can it retrogress?

Numerical modelling via the progressive mechanism approach can help determine the critical unloading at the toe of a slope, the retrogressive distance of a failure, and even the pattern of horst and graben structure after a slide. The applicability of a large deformation FE modelling technique can be extended to other types of sensitive clay landslides because this approach focuses on the propagation of shear bands. The most recent studies based on this modelling technique continue to further our understanding of the mechanisms behind all types of retrogressive landslides in sensitive clays.

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