Chapter 13

A Review on Enhanced Stability Analyses of Soil Slopes Using Statistical Design

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ABSTRACT

This chapter deals with the application of experimental design in slope stability analysis. In particular, focus of the present chapter is on the application of Box-Behnken statistical design for assessment of stability of slopes in homogeneous soil (general case), for estimation of slope stability in clay-marl deposits at the edge of Neogene basins (case study) and for the extension of grid search method for locating the critical rupture surface. Extensive statistical analysis, internal and external validation imply high estimation accuracy and reliability of developed mathematical expressions for slope safety factor and for parameters of location of critical rupture surface. Main advantages and limitations of the proposed approach are thoroughly discussed with suggestions for main directions of further research.

INTRODUCTION

In present chapter, potential application of a statistical design in stability analyzes of soil slopes is examined through three stages:

- General application;
- Solution of a specific case from engineering practice;
- Improvement of an existing method for locating a critical rupture surface.

In the first stage, analytical model for prediction of slope safety factor is proposed as a function of slope geometry (slope height \( H \) and slope inclination \( \beta \)), soil properties (unit mass \( \gamma \), soil cohesion \( c \) and angle of internal friction \( \phi \)) and water conditions (pore water pressure coefficient \( r_u \)). As a reader will see, developed model represents a simple mathematical expression of higher prediction accuracy when...
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compared to the existing models. Results obtained imply a positive effect of shear strength parameters and negative effect of slope geometry, unit mass and water conditions on slope stability. Thereby, positive effect of a single parameter on slope stability actually implies that slope stability increases with the increase of the chosen parameter value. On the other hand, negative impact of a certain parameter indicates a decrease of slope stability with the increase of a parameter value. Results of the performed analysis also indicate that the impact of soil cohesion depends on the slope geometry, unit mass and angle of internal friction. Also, the influence of angle of internal friction is conditioned by the slope inclination and water conditions.

In the second stage, derived model describes the impact of main properties of clay-marl deposits on slope stability at the edge of Neogene basin in Belgrade (Serbia). Derived model is defined as a nonlinear function of the same slope and soil parameters as in the first stage, including the effect of bedrock depth $d$ by introducing the dimensionless parameter $d/H$. Results obtained indicate that all examined properties of clay-marl deposits have a statistically significant impact on slope stability. Thereby, linear effect of influential parameters is predominant, while slope geometry and soil cohesion also show significant quadratic influence. Results of the performed research further indicate that the effect of slope height on its stability strongly depends on slope inclination, soil cohesion and bedrock depth. On the other hand, impact of slope inclination on its stability is influenced by soil cohesion and bedrock depth.

In the third stage, statistical design is used for extension of grid search method for locating the rupture surface. This is done by deriving separate analytical expressions for slip center grid $(x_{\text{min}}, y_{\text{min}}; x_{\text{max}}, y_{\text{max}})$, where one could expect to find a global minimum of slope safety factor. For the determined slip center grid, separate prediction models are derived for the corresponding ranges of slope safety factor and slip circle (rupture surface) radius. Developed mathematical expressions describe the dependence of slope safety factor on the same parameters of slope geometry, soil properties, water conditions and soil geneity as in the second stage. Obtained results indicate strong linear and quadratic effect of slope inclination on the location of slip center grid and corresponding safety factor. Moreover, location of slip center grid is strongly dependent on the slope height and angle of internal friction, latter of which also affect the value of slope safety factor in co-action with soil cohesion. Results of the analysis also imply that the effect of slope inclination is strongly affected by slope height, bedrock depth, water conditions and angle of internal friction. Impact of cohesion is conditioned by the influence of unit mass and slope height.

The main goal of this chapter is to provide a basic insight into the essence of the statistical design and its potential use in geotechnical practice. In particular, results obtained indicate that application of statistical design in slope stability analysis results in development of convenient prediction models for slope safety factor and for the location of critical slip surface, enabling in the same time the estimation of the effect of geometrical properties (slope height and inclination), soil properties (unit mass, soil cohesion and angle of internal friction), water conditions (pore water pressure coefficient) and soil geneity (homogeneous soil and the impact of bedrock depth) on the slope stability.

Chapter is organized as follows. Extensive literature review is given in section 2, while applied methods are briefly described in Section 3. Study on general application of statistical design in stability analysis of slopes in homogeneous soil is given in Section 4, together with the comparison with existing prediction models. Application of statistical design for solving a specific case from engineering practice is provided in Section 5. Application of statistical design for improvement of grid search method is given in Section 6. A brief review of the obtained results including the main advantages and limitations of using statistical design in geotechnical practice is given in the final section.