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Assessment of slide surface and pre-slide topography using site investigation data in back analysis

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1. Introduction

Probably the most reliable method of determining the strength of a soil and rock mass is to back analyze a failed or failing slope.[1,2] This method is used in geotechnics for estimating the geotechnical parameters of the rock and soil mass,[3–5] but it requires that the failure mode is well established and that there is complete and precise information available on the slide surface and the sliding mass.[6] Measurement of the failure surface geometry combined with knowledge of the slope profile before failure provide the basic information required for a back analysis.[2,7] The post-slide topography is another key factor.

The back analysis process for determining the actual strength parameters of soil or decomposed rock masses after a landslide requires knowledge of the sliding mass geometry, both before and after the sliding event, as well as the geometry or the real profile of the sliding surface. Many studies have reported in the literature the application of back analysis for determining geotechnical and geomechanical parameters of rock and soil mass,[3–5,8] but they generally present little information about the geometry of the slide surface or about the weight of the rock and soil mass that had slid, even though these factors are the most important parameters for the back analysis process. Liang and Xue-song[9] have determined the slip surface having the minimum factor of safety (called critical slip surface in deterministic analysis of slopes) and the slip surface with the minimum reliability index (called critical reliability slip surface), but they have not considered the actual profile and geometry of the slide surface. Rocscience[10] proposes the back analysis option in the slide software for slope stability studies, but it requires an imposed slide surface as input; alternatively, one can estimate by a finite element analysis the surface with the minimum factor of safety. However, this estimated surface is very likely different from the actual sliding surface, considering the uncertainties in input data of the finite element method.

Pre-slide topography can be determined using several reference points on outcrops of the slide mass that can be virtually moved backward to their initial state. By using the movement in these reference points, combined with the post–slide topography, one can define the pre-slide topography. The profile of the sliding surface generally does not show a regular circular or oval shape, but rather an irregular curve,[6,7] and the determination of this profile requires further analysis. Geophysical methods and drilling could be used for this purpose, but the feasibility of these methods is limited for a number of reasons. For one, these methods are very expensive, and secondly, the installation of drilling systems in the field could be very dangerous because it could reactivate the sliding process. Moreover, these methods do not provide an estimate of the pre-slide topography of the terrain. These two objectives are the focus of the methodology proposed in this paper, which will be presented using the case study of the Maskun

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landslide, located along the Kerman-Jiroft road in Iran.

2. Maskun landslide

The Maskun landslide occurred in the residential area of "Mohammad Abad Mskoon", located along the Kerman-Jiroft road in Iran. The main slide happened in the summer of 1999 after ground cracks had formed and led to several damaged buildings and the destruction of a road at the foot of the hill. This sliding mass is still active as of 2015, and the slow, continual slide causes problems such as traffic or motor vehicle nuisance, worried residents and the potential collapse of the power tower on the top of the hill.

The landslide mass (Fig. 1) consists of a combination of rock and soil with a total weight of more than 0.5 million tons. According to IAEG's data,[11] its length of center line is 320 m, the height of the main scarp is 7 m, and the slide widths at the crown, middle and toe of the slide are 50, 100, and 60 m, respectively. The crown is located 30 m lower than the hill apex.

To determine the pre-slide topography, the measurement of movement at particular points of the sliding mass are determined, and by statistical process some equations are obtained, which present the degree of displacement of each point according to its location. These equations are then used to estimate the displacement of all surveyed points on the slide topography to determine the pre-slide topographic map.

To determine the slide surface, a number of vertical sections are constructed by using outcrops of the sliding surface and other landmarks. Because each section shows the slide surface in a particular direction, the 3D geometric shape of the slide surface can be obtained by combining all of the sections.

3. Determining the pre-slide topography: procedure and results

The principle of this process is to modify the coordinates of the surveyed points on the sliding mass by the same amount as their actual displacement during the slide event. This process requires a measurement of the displacement to be determined for each point on the sliding mass. Mathematical relations are first developed for points whose initial location is both readily available and the measurement of displacement is accessible. Such points can be found in places such as an outcrop on the slide surface, as well as

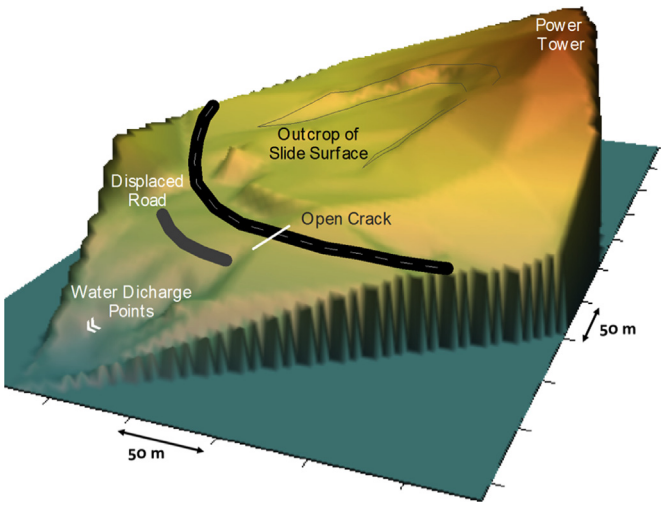

Fig. 1. Maskun landslide and its features.

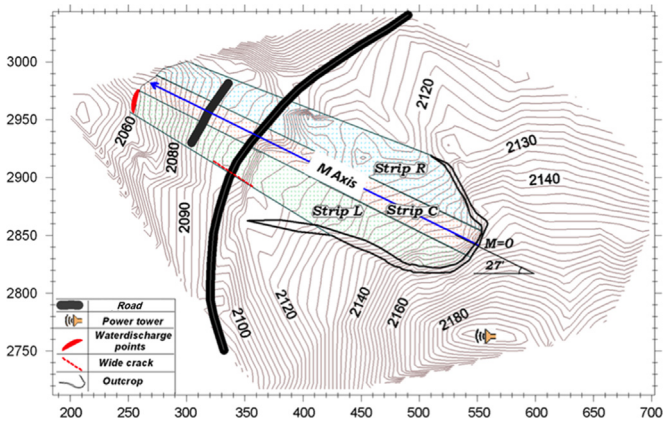

Fig. 2. Individual regions of the Maskun slide for determining the pre-slide topography.

structures such as roads, water transportations ditches, and so on. The significant characteristic of these structures is that parts of them have been displaced with the sliding mass and the rest remain in their initial location, out of the slide zone.

The sliding mass of the Maskun landslide is divided into three parts (Fig. 2) because of the complicated topography and the heterogeneous properties of the material, so that displacement measurements at all points of each part are the same. These parts form three narrow strips: the right strip (R), the central strip (C) and the left strip (L). The M axis is defined as the center line of the sliding mass, in the N63W direction. The slide direction at all points is nearly parallel and in the direction of the M axis. This is suggested by the parallelism of the cracks, which are perpendicular to that direction and are observed at different locations on the sliding mass. The long main scarp and the displaced part of the road are still observable (Fig. 1).

Pairs of identical points are chosen from these displaced entities and the following data are noted for each pair of points using the post-slide topographic map (Fig. 3): The horizontal distance of the point from the crown in the direction of mass movement (M); The measure of horizontal movement of the displaced point with respect to the other point of every pair, or, in other words, the

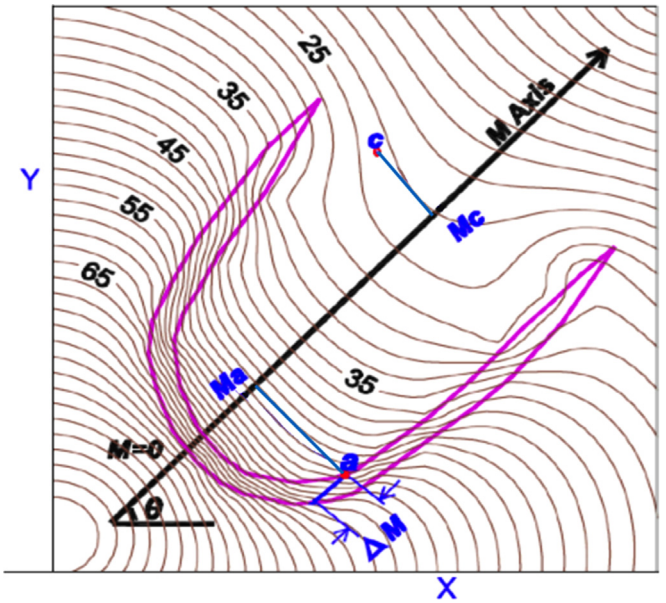

Fig. 3. Schematic illustration of the features of a slide zone.