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# Sensitivity analysis for parameters of a monitoring system for steep slopes of open-pit mines

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**Abstract:** Monitoring the stability of steep slopes of open-pit mines is a major issue relating to production safety in mines. In order to determine the technical parameters of a new type of supervising system applied in monitoring steep slopes of open-pit mines, the MSARMA method was used to establish analytical models for the monitoring system, given various parameter settings based on the description of mechanical monitoring principles. We used this sensitivity analysis to conclude that the setting of the most sensitive location of a mechanical monitoring system should be within a range of 1/5~1/2 of the lower part in a vertical direction of steep slopes, with a rational and feasible range of the dip angle setting between 0°~20°. Given the analytical results of our on-site experiments, we have shown that the parameters determined reflect the stability of steep slopes accurately and effectively. These conclusions provide a basis for the application of a new type of steep slope stability monitoring technology in open-pit mines.
**Keywords:** open-pit mine; steep slope; monitoring system setting; parameter analysis

## 1 Introduction

Open-pit coal mining is, *a priori*, the development strategy of the coal mining industry in China where the size of open-pit mines is rapidly expanding and developing[1–2]. With progress in excavation of coal sources and science and technology, not only does well mining become deeper, even the depth of excavation of open-pit mines is increasing. Due to limitations of mining slope boundaries, high slopes inevitably appear. Frequent occurrences of landslides and geological disasters in stopes, due to land surface deformation, interrupt not only normal production of mines and cause enormous losses to the economy and property of our country, but also seriously threaten the safety and lives of people operating the mines[3]. Therefore, monitoring and forecasting of slope instability of open-pit coal mine stopes become key issues in safe production of mines. The development of a "Remote Real-time Monitoring System of Landslide Disaster" by the Geotechnical Research Center of the China University of Mining and Technology (Beijing) has realized the stability status of slopes wirelessly by real-time monitoring and measuring the balance between sliding and anti-sliding forces of slopes. These forces can be reflected by monitoring changes in the tension of anchor cables. The settings of spatial parameters of the monitoring anchor cable, such as vertical location, dip angle etc. are of importance in monitoring slope stability and forecasting landslides.

## 2 Monitoring principles and mechanical models

### 2.1 Monitoring principles

Relevant literature abounds with discussions of the relationship between the stress of pre-stressed anchor cables and the stability of slopes[4–10]. The rock above the damaged surface of a slope-slide is called the landslide body and the part below the landslide bed. Before the occurrence of slope-slides, the internal stress of rocks of the slope changes continuously until the rocks become so deformed that they slide when the sliding force is larger than the anti-sliding force inside the rocks[11–12]. The monitoring method introduced a force that perturbs the mechanical system of the slope, which reflects stability of the slope by sensing the changes of the perturbance and the sliding force.

Perception of this perturbance is realized by a pre-stressed monitoring anchor cable. The continuously increasing perturbance indicates that the slope is being damaged or tending to become damaged. The

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rate of slope damage, producing this sliding trend, is reflected by the rate of growth in the force of the perturbance.

### 2.2 Mechanical models

Fig. 1 shows the sketch map of the mechanical remote monitoring system indicating that the interaction between the overhead landslide body and the lower landslide bed of the surface, damaged by landslide and the intensity of the sliding force, can be reflected by this perturbance. Perturbance is reflected by the monitoring anchor cable passing through the surface of a landslide and the landslide bed anchor.

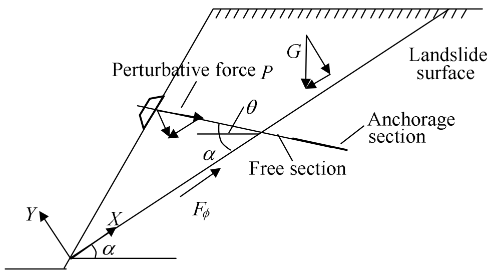


Fig. 1 Mechanical monitoring system of perturbance

Fig. 2 shows the principle of the mechanical relationship between the sliding and perturbative forces of the slope.

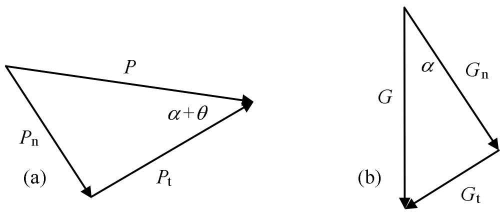


Fig. 2 Perturbative force monitoring mechanical functions

The trigonometric relationships of the mechanical functions shown in Fig. 2a are as follows:

$$P_t = P \cdot \cos(\alpha + \theta)$$

$$P_n = P \cdot \sin(\alpha + \theta)$$

where $P$ is perturbative force, or remote monitoring value, kN; $P_n$ normal component of the stress of the monitoring anchor cable along the sliding surface, kN; $P_t$ tangential component of the stress of the monitoring anchor cable along the sliding surface, kN; $\alpha$ subtended angle between sliding surface and level surface, (°); $\theta$, anchorage angle, (°).

The trigonometric relationhips of the mechanical function shown in Fig. 2b are as follows:

$$G_t = G \cdot \sin \alpha$$

$$G_n = G \cdot \cos \alpha$$

where $G$ is weight of sliding body, kN; $G_t$ tangential component of the weight of sliding body along the sliding surface, kN; $G_n$ normal component of the weight of sliding body along the sliding surface, kN.

When the slope of the rock has reached its critical equilibrium, the following balanced relationship among tangential forces of the sliding surface exists:

$$G_t = P_t + F_\phi$$

where $F_\phi$ is the friction resistance exerted on the sliding body by the sliding surface (kN):

$$F_\phi = (P_n + G_n) \cdot \tan \bar{\phi} + c \cdot l$$

By arranging these two equations, we obtain the following mechanical perturbation monitoring relationship:

$$G_t = P\left[\cos(\alpha+\theta) + \sin(\alpha+\theta)\tan\bar{\phi}\right] + G\cos\alpha\tan\bar{\phi} + cl$$

where $\bar{\phi}$ is average weight of friction angles inside the clay layers of the slope sliding body, (°); $c$ cohesive forces between the clay layers of the slope sliding body, kPa; $l$ length of the sliding surface, m.

This formula expresses the relation between the sliding force and perturbation when the slope is at its critical equilibrium.

## 3 Parameter sensitivity analysis of monitoring anchor cable

The pre-stress changes of the monitoring anchor cable are affected by the location and angle of the cable when the stability of the slope changes. Therefore, it is important for accurate monitoring of slope stability to install the anchor cable at its most sensitive location and its most sensitive angle. For a monitoring slope section, the location of the anchor cable largely refers to the height relative to the bottom of the slope and the angle mainly refers to the subtended angle with the level surface. We have applied here the analytical MSARMA system of the Geotechnical Research Center of the China University of Mining and Technology (Beijing) in sensitivity analysis to determine the location and angle of the slope monitoring anchor cable.

### 3.1 Brief introduction to the MSARMA analytical system

Analysis of slope stability by SARMA is a traditional analytic method based on limit equilibrium theory. The basic principle is that the slide-slope or slope moves as a complete rigid body only if it is sliding on an ideal plane or circular surface, otherwise it will be broken into relatively smaller sliding blocks which move together so that the sliding blocks should not only overcome shear the strength of the sliding surface, but also their own strength as shown in Fig. 3.