Principles of using precise inclinometry for landslides

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Abstract. The main goal of this article is to analyze the possibility of using precise inclinometry for landslides. Inclinometric measurements are widely used to monitor landslides, retaining walls, piles and in places where it is necessary to measure deep ground deformations. The value of deep-seated ground deformations is calculated indirectly by using the difference of the inclination of an inclinometer casing installed on a borehole. Inclinometers are used to measure horizontal movements at various levels, usually within earth fills. Inclinometers are used to monitor slopes, indicating movement on a slope before it is visible on the surface of the slope. Inclinometers have often proved very successful in recognizing movement zones and the size, speed and direction of movement not only on slopes, but also on embankments, etc. There are a number of different types of inclinometers, and within each type there are variations produced by different manufacturers. However, the basic principle of precise inclinometry is the same. A guide tube is installed in the borehole and the inclination of the guide tube from the vertical is measured at predetermined intervals. It is measured using a pendulum which is enclosed in a watertight probe. The probe is lowered through the tube. The inclination of the pendulum is measured using electronic devices that are very accurate. The measurement results are determined by pulling out the measuring instrument (inclinometric probe). After assessing the measured values, the course of the profile is determined, if we compare the profiles from different measurements, we can evaluate the direction and size of the shift for the monitored period.

1. Introduction
Accurate inclinometry is one of the methods of geotechnical monitoring, which is understood as the control and observation of a landslide over time. With the help of geotechnical monitoring, we can detect not only changes in the speed of landslide movement, but also changes in physical properties and mechanical properties in the landslide zone, as well as changes in the geometry of the slope. If the slope on which the landslide has already been rehabilitated, geotechnical monitoring is used here to check the functionality of the remediation measures used. Geotechnical monitoring is a long-term process and monitoring usually lasts for more than decades.

Precise inclinometry is used to measure the horizontal deformation in the borehole caused by movement on the shear surface at depth. It is the most reliable and common method for measuring horizontal displacements and their directions in a rock and earth body. Measurement allows you to monitor the directions and magnitude of movement, if we repeat the measurement, we can also determine the speed of movement. The device consists of a measuring probe, a connecting cable and a recording unit. [1]
2. Precise inclinometry

The principle of inclinometric measurement consists in measuring the inclination of the guiding inclinometric probe (Figure 1), which is provided with a small weight and is usually 0.5 to 1.0 m long with a diameter of 25 to 30 mm. We install inclinometric casings (material PE, PVC, Al, etc.) with a diameter of 40 - 70 mm with special guide grooves in the pre-prepared inclinometric borehole. The grooves are milled on the inside of the casing and must be perpendicular to each other. The inclinometric probe has wheels in its upper and lower part, which are used to insert into the grooves of the casings of the inclinometric borehole. The bottom of the well should be placed in a stable geological subsoil to avoid distortion of the measurement results.

The connecting pipes are connected together using special aluminum rivets. The riveted joints must be thoroughly covered with sealing tape to ensure a thorough seal and to avoid the possible ingress of dirt (cement, soil, etc.). The intermediate ring of the drilling rig and the outer walls of the casing are homogenized in the completed well based on the geological composition of the massif of suspensions (clay, cement, bentonite, gravel). [2][3]

![Figure 1. Principle of measurement by inclinometric probe](image)

The measurement results are determined by pulling out the measuring instrument (inclinometric probe) in steps given by the length of the instrument (eg 0.5 m). After assessing the measured values, the course of the profile is determined. If we compare profiles from at least two measurements in different terms, we can evaluate the direction and magnitude of the shift at different depths for the observed period. [2]

The material from which the inclinometric guide casings are made varies depending on the purpose of the measurement. The first type of inclinometric guide casings are casings that are made of ABS plastic. These casings have an outer diameter of the joints (67 mm). This type of casing is used for long-term repeated measurements. Although they have less internal stability, they localize small deformations well.[3]

The second type are guide casings, which are again made of ABS plastic, but their outer diameter of the joints is larger than in the previous case, namely 94 mm. These casings are mainly used for horizontal boreholes, where horizontal casings with horizontal probes are used. They are used, for example, in embankments of dams, etc. Due to the larger diameter of casings, this type allows the passage of the probe even where there was a greater unformation of pipes. [3]
The third type is guide casings, which are cooked from aluminum. These casings find their application where inclinometric measurements are required for maximum accuracy as well as measurement speed. Unlike the previous material, this material has greater internal stability, but it is harder to locate small deformations with these casings. Other disadvantages of aluminum include the fact that they are subject to corrosion and at greater depths this material may cause a small twist of the casing ($\pm 5^\circ / 30$ m). [3]

The fourth type of inclinometric guide casings are casings that are made of PVC. This type of casing is characterized by a larger inner diameter of the casing, which allows better passage of the probe even where the casing has deformed. This type of guide casing is used for both horizontal and vertical measurements. [3]

Based on the inclinometric measurement, we find the result, which is a graphic output with marked values of displacements in two measured directions, which are perpendicular to each other. This result is displayed on the electrical recording unit.

We can use two methods to evaluate the result of inclinometric measurements. The first method is called the difference line, in which the difference in horizontal displacement from the first measurement is plotted for each measured step.

The second method consists in plotting the total displacement line from the bottom of the borehole upwards. At the location of the shear surface, an increasing increase in displacements then manifests itself with each subsequent measurement. Figure 2 shows both ways to evaluate the results.

![Figure 2. Evaluation of inclinometric measurements](image)

The inclinometric casing may be damaged or seated incorrectly during installation. Incomplete fixation of the casing with cement grout leads to incorrect or distorted measurement results.
This is a problem when the head of the measuring casing to which the previous measurements are tied is destroyed. This problem can be solved because the reference point is at the bottom of the borehole. However, it is necessary to know the original length of the installed inclinometric casing.

3. Measurement procedure by using precise inclinometry

The common measuring apparatus (Figure 3) used for precise inclinometry consists of a measuring probe, a supply cable and a readout unit (support unit). To evaluate the results, a suitable PC or laptop with software that evaluates inclinometric measurements is required. [4]

![Figure 3. The measuring apparatus used for precise inclinometry](image)

There is also a special type of inclinometer that measures in boreholes up to a depth of 500 m. This inclinometer consists of a trailer in which a drum with a wound measuring cable is placed. Furthermore, an electric motor is located in the trailer, which controls the drum with a cable, a reading device and a 2 m long probe. [3]

The main element of the whole measuring device is an inclinometric probe (Figure 4), which is inserted into the inclinometric borehole and measures the inclination of the guide tube from the vertical [5]. The measured data are sent by the measuring cable directly to the reading device. Conventional measuring probes measure in steps. These steps are determined by the length of the device (e.g. 0.5 - 1.0 m). Inside the probe, which is made of metal, a very sensitive sensor is located. This sensor can measure the level of inclination using a special torque system. The measuring probe is equipped with two wheels at each end of the probe. The distance between these pairs of wheels is referred to as the length of the measuring probe. Using these wheels, the probe is inserted into the grooves of the guide casing, which is located inside the borehole. [4]
Another important part of the measuring apparatus is a drum with a wound measuring cable. The cable triggers the probe inside the borehole and transmits the data that the probe measures directly to the readout unit. Normally, drums with a wound measuring cable are divided into two models. The first type is a heavy drum model, which includes a crank and a mechanical brake. This model uses a cable that reaches a depth of 500 m. If we measure at great depths, a drum with a measuring cable is used, which is wound by a motor. The second group is a lightweight model of a drum with a measuring cable, which reaches a maximum length of 200 m. [3][6]

If we do not have a readout unit (Figure 5), we need a support unit as an alternative solution. The support unit supplies electricity (12 V batteries) to the measuring system. The support unit cannot store the measured data itself, but stores it in the memory of a PC or laptop, which must also be connected to the support unit during the measurement. The reader unit is able to save the measured data even without a connected PC and also contains a battery, so no external power source is needed. After measuring the data, the reading unit is connected to a PC, where the measured data are downloaded using a cable. We then further process the measured data using special software as required. [3][6]

![Figure 4. Probe measurement principle](image)

![Figure 5. Readout unit used for precise inclinometry](image)
4. Conclusions
Precise inclinometry was designed to reduce risks to human health and buildings. However, if the measurement is performed incorrectly or the correct procedures are not followed, we may get inaccurate measurement results. Inclinometers have often proved very successful in recognizing movement zones and the size, speed and direction of movement not only on slopes, but also on embankments, etc. The inclinometric casing may be damaged or seated incorrectly during installation, measuring casing to which the previous measurements are tied could be destroyed, so we have to be careful. Precision inclinometry measurements are based on the principle of changing the position of the probe in the borehole, which is the physical principle of the pendulum and the change in motion is monitored by gradually changing the position of the probe and connecting cable to the surface and this change is evaluated over time. The evaluation can be proved by a sum or a difference line.

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