

## **Instrumental Monitoring of Slopes**

**Key Messages :** Slope instrumental monitoring is commonly applied in various aspects under Hong Kong's landslide risk management system. It provides useful information for slope stability assessment and design as well as assessing effectiveness of special slope stabilisation measures. Since there is a strong correlation between rainfall and landslides in Hong Kong, the GEO also continuously monitors rainfall with raingauge stations distributed throughout Hong Kong to assess if the Landslip Warning should be issued. The GEO continues to undertake technical development to explore the applications of innovative slope instrumentation technologies for further enhancing landslide risk management practice.

### **Introduction**

Slope instrumentation plays a notable role in Hong Kong's landslide risk management system. Different techniques have been adopted for various purposes based on their capability, nature of monitoring, slope and hydrogeological conditions and slope failure or ground deformation mechanisms. In addition, over the past years, the GEO has been trialling innovative slope instrumentations to explore more practical and effective slope monitoring techniques.

Typical applications of instrumentation monitoring for slope safety in Hong Kong include:

- Monitoring for slope stability assessment and design;
- Monitoring for assessing effectiveness of special slope stabilisation measures;
- Monitoring of slopes of particular stability concern or unusual characteristics;
- Automatic monitoring of rainfall for territory-wide Landslip Warning System

### **Monitoring for Slope Stability Assessment and Design**

Groundwater monitoring is crucial for the stability assessment of existing slopes and the design of new slopes or slope improvement works. Slope instrumentation for such purpose has been adopted widely in Hong Kong since the late 1970s. Details of installation are usually specified by the geotechnical professionals who are responsible for assessing slope stability and designing the slopes works. The conventional method used to obtain groundwater information is manual measurement using piezometers or standpipes installed in boreholes. Automatic groundwater monitoring devices with remote data transmission is becoming more common, especially at slopes in remote areas or in situations where real-time and a more complete record of groundwater level changes over a period of time are needed.

### **Monitoring for Assessing Effectiveness of Special Slope Stabilisation Measures**

Regular monitoring may be necessary if the long-term stability of slopes relies on special measures such as pre-stressed ground anchors and horizontal drains. These special measures could become less effective with time unless they are properly maintained, so regular monitoring of their effectiveness is important. This type of monitoring is normally undertaken by the slope owner, who could be a government department or a private party, and it helps to

determine the type of slope maintenance required.

A special example of this category was applied at the Po Shan hillside in the Mid-levels, where over 70 horizontal drains (up to 90 m long) were installed in the area in 1984-1985 to lower the groundwater table in order to improve the stability of the hillside against large-scale deep seated slope failure. The drains have satisfactorily served the intended purposes in drawing down the groundwater table, but subsequent monitoring data in the early 2000s showed that some of the horizontal drains, which were more than 20 years old, exhibited a decreasing trend of outflow in recent years. Consequently, reprovisioning of a more robust and sustainable groundwater drainage system, which comprised an underground tunnel system with sub-vertical drains to regulate the regional groundwater regime, was completed in 2009. As a health monitoring of the Po Shan drainage tunnel, an automatic real-time groundwater monitoring system has been established, with an automated pressure relief device provided to control the groundwater levels within a pre-defined safe range.

### **Monitoring of Slopes of Particular Stability Concern or Unusual Characteristics**

Landslides in Hong Kong are usually brittle in that most landslides occur rapidly during heavy rains with very little or no prior and noticeable signs of distress or movement. Under these circumstances, systematic slope instrumentation may not be practical for monitoring the possible onset of landslide development at individual slopes for the purpose of giving warning of impending danger. Occasionally, however, when an individual slope has become a cause of concern because it shows evidence of significant past movement or continuing movement, the slope owners or the GEO may monitor certain pertinent critical aspects such as ground movements and groundwater levels. A contingency plan may be put in place with predetermined trigger levels for actions, e.g. cordoning off of potentially affected areas.

The usual methods of monitoring ground movement in Hong Kong are by installing inclinometers or extensometers in boreholes, measuring surface displacement between survey points across tension cracks and measuring movement of targets on slopes using surveying instruments or airborne photogrammetry. Innovative instrumentation using fibre optic sensors and Global Navigation Satellite System can also be employed to monitor ground movement or geotechnical structure deformation. Remote sensing methods (e.g. digital photogrammetry, Light Detection and Ranging (LiDAR), radar interferometry) with geographical information system software has also been used in Hong Kong.

While monitoring slopes of potential stability concern is commonly an interim or precautionary measure, subsequent remedial action plan is necessary to address the potential stability concern so as to make the slope safe in the long term. Upon completion of the remedial works, monitoring is normally no longer necessary.

### **Automatic Monitoring of Rainfall for Territory-wide Landslip Warning System**

As most landslides in Hong Kong are triggered by rainfall, the GEO operates a territory-wide Landslip Warning System, which uses real-time rainfall data and rainfall forecasts as the basis for issuing the Landslip Warning, so as to alert the public to reduce their exposure to possible danger from landslides and also to trigger the emergency response systems within government departments, e.g. mobilisation of the GEO Emergency Control Centre, to deal with landslide incidents.

The GEO operates a raingauge system, which comprises an extensive network of about 90 automatic raingauge stations throughout Hong Kong, to provide real-time rainfall information for use in the Landslip Warning System. Together with other raingauge stations operated by the Hong Kong Observatory (HKO) and the Drainage Services Department, more than 100 raingauge stations collect real-time rainfall data automatically and the data are transmitted to the GEO's cloud server at one-minute to five-minute intervals via mobile telephone networks. The collected rainfall data are stored and processed using cloud computing service that predicts the level of landslide risk at five-minute intervals, based on which the GEO and the HKO will assess if the Landslip Warning should be issued.

As at now, making use of rainfall monitoring to assess the likelihood of occurrence of landslides is still the most effective way of providing the public with a warning of increased landslide risk during periods of heavy rainfall.

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