

# Use of Inclinometer for Landslide Identification with Relevance to Mahawewa Landslide

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**ABSTRACT:** Instrumentation can be used to characterize the location of shallow and deep failure planes as well as measure the direction of landslide movement. Subsurface movements or ground deformations can be characterized in a variety of ways using different sensor technologies and data acquisition methods. Inclinometer can acquire subsurface movements automatically at frequent time intervals and provide a useful tool for geologists and engineers to enhance subsurface characterization, improve geotechnical design, and monitor construction activities in real time. The Mahawewa landslide is a massive slope failure that is partial reactivation of ancient landslide in Walapane of Nuwaraeliya District. In January 2007 and February 2011 the landslide was reactivated. From July 2010 to present, we have conducted monitoring of installed instrument and general geological inspection. Ongoing monitoring has revealed that the landslide movement continues after the 2007 reactivation and still continues movement can be observed. We have identified two slip surfaces at the head of the landslide according to the analyzed inclinometer data. The landslide head shows a slump and the toe part is a debris flow. Therefore this can be categorized as a complex landslide. Both the acceleration stage and the failure stage of this landslide show correlation to rainfall. Hence to control this landslide have to control both surface and subsurface water.

## 1 INTRODUCTION

The Mahawewa landslide is a massive slope failure that is partial reactivation of ancient landslide in Walapane of Nuwaraeliya District. In January 2007 and February 2011 the landslide was reactivated (Fig 1). Geologically this slope can be categorized as a scarp slope and the whole area is covered with thick colluvial soil layer. The slide length is about 1.5 km and the width is about 250m. There are about 65 families were resettled due to this vulnerability of Mahawewa landslide. Agricultural lands and Irrigation canal systems also damaged by the landslide. Kumbalgamuwa Keerthi Bandara Maha Vidyalaya, the main access road from Walapane to Kandy and the community of the underlying areas are still at a high risk. Preliminary investigation reveals that most of the houses and grounds have developed cracks due to both vertical and horizontal movements (Fig 2). Newly- formed springs and underground flow paths were observed in the main landslide body. This area consists of debris of very old landslide showing evidences of creeping and subsidence in the recent past.

Instrumentation and monitoring can be used to identify risk and the potential harm by determining whether landslide movements are occurring, the rates of movement with comparison of the rainfall data. Therefore NBRO collaborate

with JICA and automatic rain gauges, Strain gauges, extensometers, inclinometer and piezometer were installed in Mahawewa area for monitoring the surface and sub-surface movement to study the controlling characteristics of the landslide.(Fig3) The study mainly deals with the appropriate mitigation measures for Mahawewa Landslide base on the instrumental results, geological and environmental conditions.

The inclinometer is a device for monitoring the onset and continuation of deformation normal to the axis of the borehole casing by passing a probe along the casing (Dunncliff 1988). Thus, an inclinometer monitors deformation normal to the axis of the casing which provides a profile of subsurface horizontal deformation. The depth at which shear movement is detected by the inclinometer is the depth of the failure surface. The portions of the casing that have not sheared represent the areas above and below the failure surface if there is one failure plane impacting the casing.

Inclinometer probes usually measure displacement in two perpendicular planes; therefore, displacement magnitudes and directions (vectors) can be calculated. The bottom end of the guide casing serves as a stable reference (datum) and must be embedded beyond the displacement zone. Relative displacement over time is determined by repeating measurements at the same depths and comparing data sets.

## 2 METHODOLOGY

### 2.1 Installation and monitoring of Inclinometer

The inclinometer installation and interpretation processes involve several important factors or steps. Therefore, the resulting measurements and difference between the zero and subsequent readings are meaningful. First, the bottom of the inclinometer must be located well below the potential zone of movement so the bottom of the inclinometer does not translate. If the inclinometer is not located well below the zone of movement, the inclinometer will not capture the total amount of movement.

In Mahawewa, a bore hole was drilled as it cross the slip surface for installed (the depth to the slip surface is determined approximately and here the slip surface was assumed to be 28.5m and drilled to about 39.5m). Second the AI pipe was inserted to the borehole sealed the connections and the other parts were connected (Fig 4). Then the inclinometer probe was inserted in +X direction (Landslide movement direction) to the bottom of the hole. Using the data logger the inclination from the vertical was measured in +X and +Y direction. After taking this set of readings then the probe is rotated 180° for take another set of  $\delta X$  and  $\delta Y$  direction data. It is important that the same probe and electrical cable should be used for take the zero and all subsequent readings. It is also preferable that the same person performs all of the readings so the results do not have any bias or unwarranted differences from the zero reading. These consistencies are important because the depth of shear movement and direction of movement are derived from the difference between the zero and subsequent readings.



Fig.1 After reactivation of the Mahawewa Landslide in 2011(debri flow and the main scar of the landslide).



Fig.2 Cracks observed in the head of the landslide.

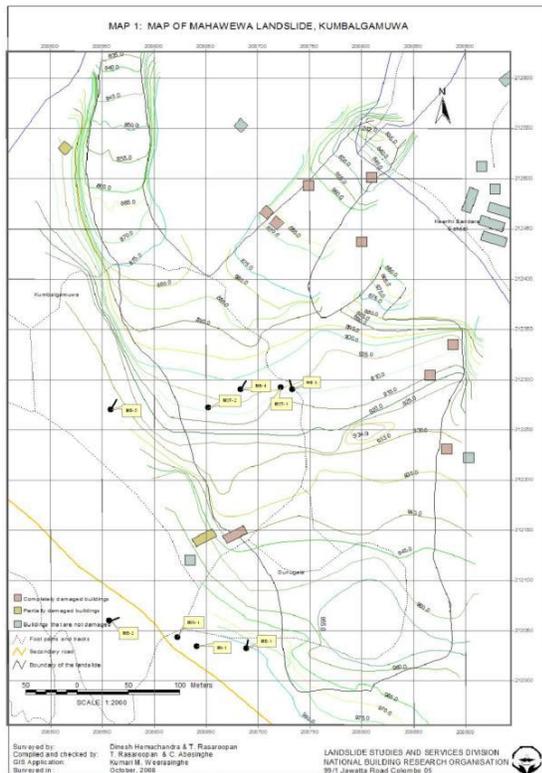


Fig.3 Map of Mahawewa Landslide with Instruments installed locations



Fig.4 Parts of the Inclinometer. A. Data Logger B. Inclinometer Probe C. Connection Cable

## 2.2 Inclinometer Data

### 2.1.1 Magnitude and the Location of Movement

The inclinometer probe does not provide horizontal movement of the casing directly. The probe measures the tilt of the casing which can be converted to a horizontal movement as shown in figure 5a. The deviation from vertical, i.e., horizontal displacement, is determined by the sine function and expressed as follows:

$$\text{Deviation from vertical} = L \times \sin \theta$$

Where  $L$  = measurement interval (0.5m);  $\theta$  is the angle of tilt measured by inclinometer probe.

The measurement interval is recommended to be the distance between the probe wheel carriages to achieve the maximum precision. The value of tilt is a function of the measurement interval.

The vertical deviation at each measurement interval is the lateral position of the casing relative to the bottom of the casing because the bottom of the casing remains fixed and does not move laterally. The deviation values can be plotted as an incremental displacement or slope change profile (i.e., slope change vs. depth) to show movement at each measurement interval. The incremental displacement profile is useful to dramatize the location of the deformation zone. A spike in this plot indicates the location of movement, i.e., the failure plane.

### 2.1.2 Direction of Movement

Determining the direction of movement is important because the critical cross-section should be parallel to the direction of movement. Knowing the direction of movement can reduce the number of cross sections that need to be considered in the stability analyses and remedial design because the various cross-sections should be parallel to the direction of movement. Locating the critical cross section is important for determining causation, back calculation of shear strength parameters, and design of remedial measures. The direction of movement can also be used to determine if the slide is moving as a single unit or not, which can facilitate determining causation and remediation.

The horizontal displacement profiles of the casing are usually determined using the data from the X- Y axes of the inclinometer casing. These axes are mutually perpendicular vertical planes as shown in Fig. 5a. The X-axis is usually oriented in the direction of slide movement during installation of the casing. Two sets of casing grooves allow the inclinometer probe to be oriented in either of two planes set at 90° to each other (Fig 5b). Thus, horizontal components of movement, both transverse and parallel to any assumed direction of sliding,

can be computed from the inclinometer measurements (Mikkelsen 1996).

If the X-axis is perfectly aligned with the direction of landslide movement, the entire shear movement will be measured in the X axis and no movement will be detected in the Y-axis. However, it is difficult to determine and align the X-axis in the exact direction of the landslide, especially if the slide is not a single unit. Thus, the actual magnitude and direction of movement are determined by vector summation of the two components of movement measured in the X- and Y-axes. The direction of the X-axis is usually determined using a compass.

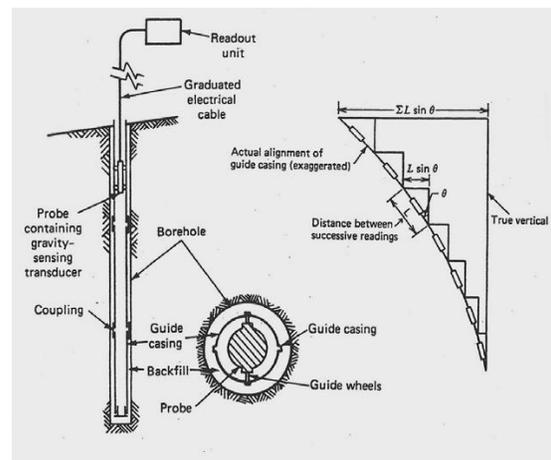


Fig 5a Schematic of Inclinometer probe inserted in casing that is installed to monitor ground deformations

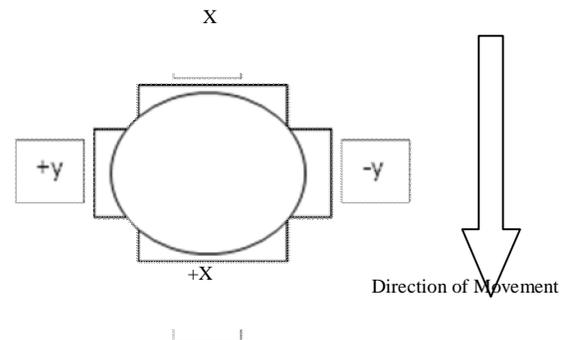


Fig 5b Alignment of X axis to the movement direction

## 3 RESULTS AND DISCUSSION

### 3.1 Surface Movement Data

Topographical Survey shows that most of the area is characterized by large superficial displacements. The rate of displacements is highly variable. The crack survey map shows the ground movement of the area (Fig 6).



Fig 6 Crack Survey Map of the area.

### 3.2 Deep Movement Data

Inclinometers can be used to detect both developing and sudden adverse movements of critical marginally stable slopes and landslide zones. Many marginally stable areas experience ground movement at creep rates that often accelerate during higher groundwater levels, possibly associated with significant periods of precipitation.

In generally Mahawewa area is influenced by North East monsoon and precipitation of 3300mm/year in average (Fig 7).

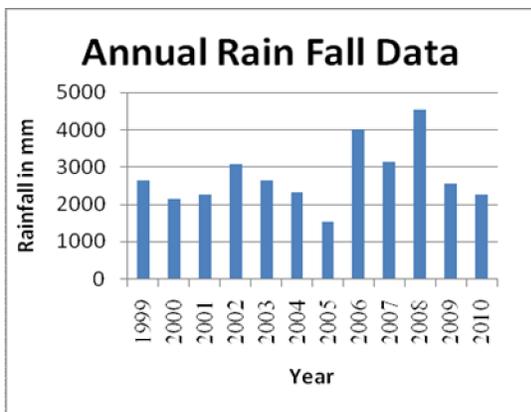


Fig 7 Annual Rainfall Data in Mahawewa Landslide Area

During the North East monsoon period the groundwater level at the location of inclinometer was increased averagely about 1.5m (fig 8a) and at the strain gauge location it was increased about 6m in average (fig 8b).

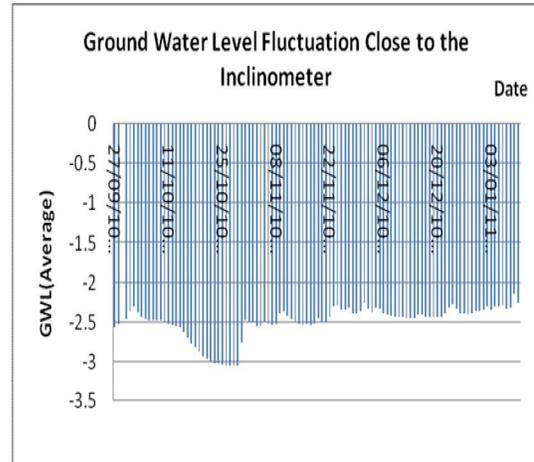


Fig 8a Ground level fluctuation close to the Inclinometer

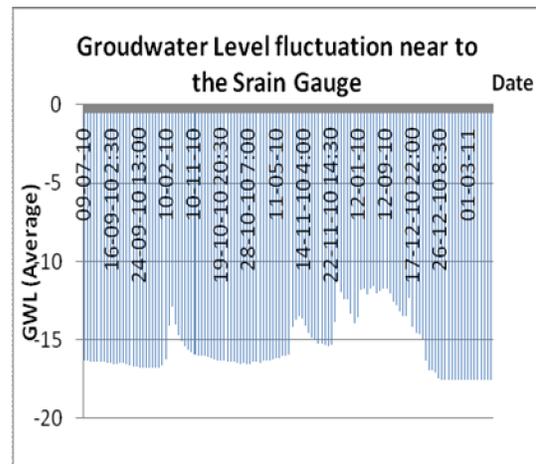


Fig 8b Groundwater Level fluctuation close to the strain Gauge

Inclinometer reveals that slope movements are occurring along different shear surfaces at different depths. According to the graph of the inclinometer data (fig 9), we can find gradual deformation from the bottom (39m) up to 27m. After this movement a big movement were occurred at the depth of 13m during the reactivation of the land slide in January 2011 and then the inclinometer tube was uplifted about 15cm(fig 10).

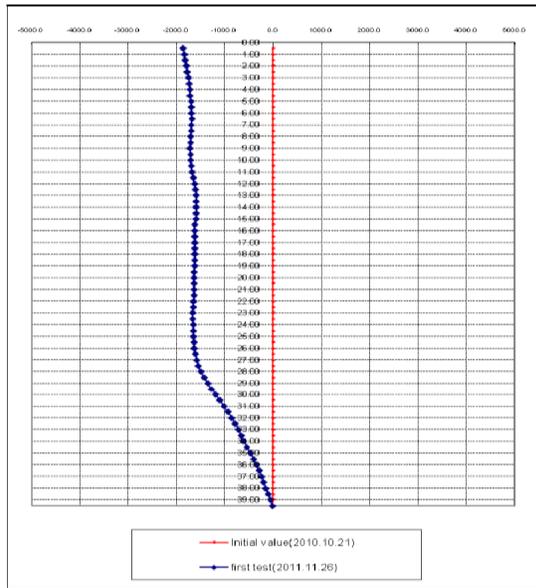


Fig 9 Graph of inclinometer Data of X-X (Displacement in mm vs depth in m) Showed deformation at depths of 13m and 27m.



Fig 10 Uplifted inclinometer tube

Strain gauge was installed at middle area of the landslide and Analytical data of the strain gauge showed another slip surface at the depth of 19m (fig 11).

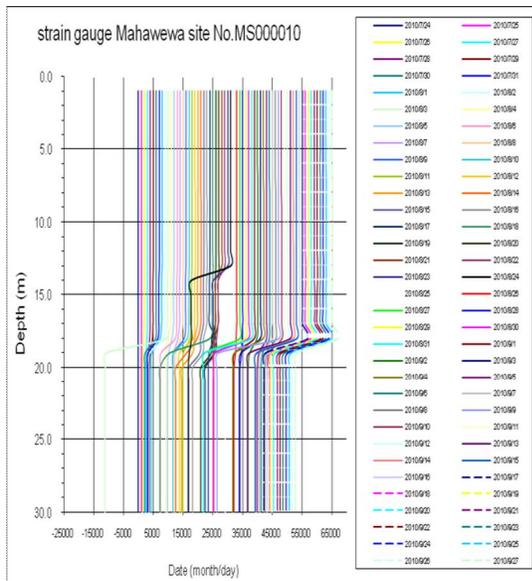


Fig 11 Graph of Strain Guage Data in Mahawewa Landslide

According to the geological and geomorphologic observation and visual on ground cracks and using analysis data possible slip surface were drawn (fig 12). Main slip surface may be deeper than 39m (beneath the inclinometer end). Debris flow (fig 13) Was occurred at toe of the landslide during reactivation on February 2011 and some ground was subsided about 2.0m on Head of the landslide.

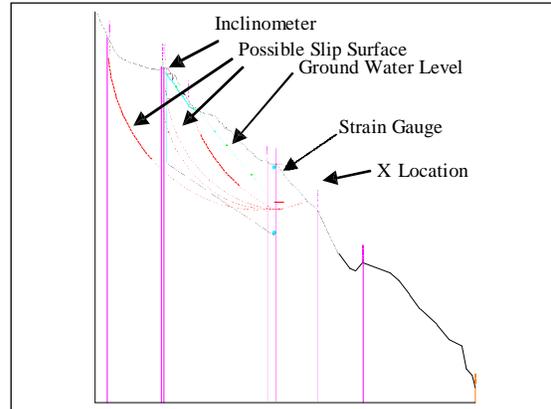


Figure 12 Possible slip surfaces in the slope area according to geological, geomorphological and visual ground crack observations



Fig 13 Debris flow which occurred at the toe of the Mahawewa Landslide

#### 4 CONCLUSION

The experimental results relative to this case history show the usefulness of monitoring system constituted inclinometer and strain gauge for sub surface displacement measurements. It is showed that the slope deformations are not controlled by an unique slip surface, but by mul

multiple shear surfaces and the rate of displacements varies along the different shear surfaces. When consider the strain gauge data it is showed that the slip surface depth is at about 19m from the ground level. And Inclinometer reveals that the slope movements are occurring different shear surfaces at different depths (depth at about 13m and 27m from the ground surface). The correlation between strain Gauge data and inclinometer measurements allows identifying the shear surfaces along which movements are occurring, while the comparison of surface and deep displacements allows identifying the kinematics characteristics of the whole phenomenon. Here the debris flows occur from x location in fig 12 near to the strain gauge and that showed the main slip surface is at the depth of 19m from the ground at the strain gauge location. But when consider the Inclinometer data there were only two slip surfaces were identified. But considering the observed ground cracks and geomorphology of the area there should be another slip surface below 27m. But our inclinometer does not record any data below 39m (39m depth is the end of the inclinometer). Due to that reason we can assume that the main slip surface should be below the inclinometer depth.

In our study two main difficulties were encountered. Borehole Depth of the inclinometer measurement is not enough. Although there were no any instruments were setup at the toe of the landslide.

Several types of systematic errors can influence the readings and produce false indication of displacement. Special care should be taken on getting the data. Such as depth positioning errors can occur. This error can occur when the probe position are shifted between two different data set. This can be avoided by understanding of the ground movement and using top reference mark.

The landslide head shows a slump and the toe part is a debris flow. Therefore this can be categorized as a complex landslide. Thickness of movable mass is about 40m at head of the landslide. This is a deep seated complex type of movement. Therefore to control the landslide have to decrease of pore water pressure. The surface water should be diverted from unstable slopes by ditches. To remove ground water has to construct deep drains which trenches are sunk in to the ground by intersecting the slip surface. But when consider this Mahawewa landslide, it would be very effective that constructing drainage tunnels. In addition large diameter pile work can be applied as retaining work for stabilized the landslide mass.

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