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Research Paper

Slope Stability Monitoring Using GSM Network System

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ABSTRACT

Slope failure due to slope instability can initiate landslides which may result in loss of lives, property, infrastructures and economic loss. There are many factors that trigger slope failure such as rainfall, hydrological condition, groundwater level and geological formation of the slope area. However, slope failures can be prevented by monitoring high risk slopes using geotechnical instruments and electronic sensors. In this study, an early warning system was developed to immediately alert the authority and the management on slope stability by installing selected slope monitoring instruments at high risk slopes with infrastructures. Slope monitoring system using wireless network is an effective method to monitor the condition of slopes especially the inaccessible slopes in unsafe areas. By applying this system, the management can reduce cost, human resources and time on slope maintenance that can efficiently notify the maintenance team on potential unsafe slopes or slope failures.

1. Introduction

Malaysia is one of the countries in South East Asia which is prone to landslides as it is situated in the tropical climate that experience high intensity of rainfall, averaging more than 2,000 mm annually (Mukhlisin et al, 2015). The increasing occurrences of slope failures always lead to massive landslides that cause the loss of human lives and extensive damage to properties and infrastructures (Kazmi et al., 2017). Some of the main factors that cause landslides or slope failures are rainfall, lack of vegetation and development of buildings and infrastructures on slope and hillsides. As an effort to reduce the number of landslide hazards and their consequences, the government agencies and private organizations have collaborated to deal with the issues by the implementation of early warning system in disaster prevention (Koay et al, 2016, Dixon et al., 2018).

Many countries have adopted early warning systems for landslide risk management (Piciullo et al., 2018, Van Khoa et al., 2018) From time to time, new techniques and latest technology were devised for an effective monitoring system such as wireless sensor network system and cloud computing (Kebaili et al., 2016, Ahmed et al., 2019). In Malaysia, transmission towers are usually located in remote areas covered by hilly topography which are extremely exposed to erosion and landslide. Thus, it is important to monitor any physical changes and phenomenon occurring on the slope. Stability of tower structure is greatly influenced by slope stability (Kim et al., 2016). The objective of this study was to develop an early warning system that can immediately alert the management on slope stability by installing selected slope monitoring instruments at every transmission tower. This network system will analyze data from the management transmission database which includes location of transmission towers, previous soil investigation report and slope layout.

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2. Study area

The study area was conducted at Kenyir-Tanah Merah, (**Fig. 1**). The site has transmission lines located on the slopes which were susceptible to soil erosion and landslides. The site was not accessible during monsoon season, therefore wireless monitoring would be effective to study the slopes.

Fig. 1. The study area at Kenyir- Tanah Merah

3. Methodology

In this study, several sensor instruments were used for slope monitoring such as inclinometers, piezometers, rainfall gauges and soil moisture sensors.

3.1 Piezometer Vibrating Wire

The Encardio-rite pore pressure meter consists of a magnetic, high tensile strength stretched wire, one end of which was anchored and the other end was fixed to a diaphragm which deflects in some proportion to the applied pressure. Any deflection of the diaphragm changes the tension in the wire, thus affecting the resonant frequency of the vibrating wire. The resonant frequency of which the wire vibrates can be accurately measured by a vibrating wire readout unit (Figure 2). The piezometer, also known as pore pressure meter, is used to measure pore water pressure in soil, earth/rock fills, foundations and concrete structures. It provides significant quantitative data on the magnitude and distribution of pore pressure and its variations with time. It also helps in evaluating the pattern of seepage, zones of potential piping and the effectiveness of seepage control measures undertaken.

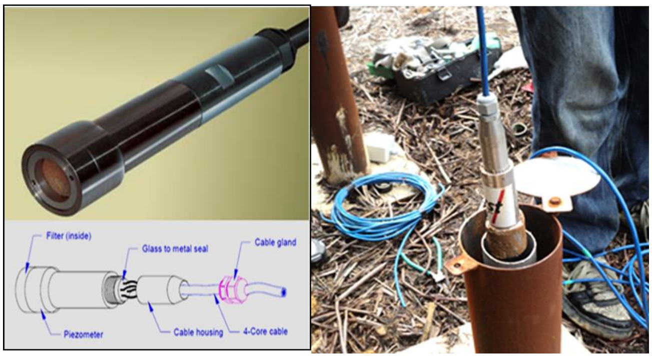


Fig. 2. Piezometer Vibrating-Wire

3.2 In-Place-Inclinometer

In-place inclinometer system was connected to a data acquisition system for continuous real-time monitoring of the movements (**Fig. 3**).

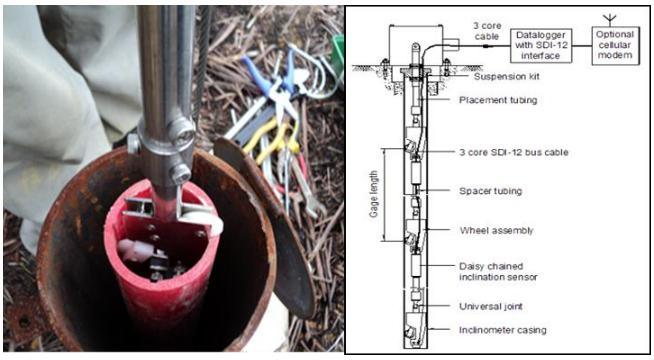


Fig. 3. In-Place-Inclinometer

Encardio-rite has two options of in-place systems for connection to data logger. In model EAN-51M system, individual signal cables from each of the in-place sensors in a string is taken to the borehole top for connection to the data logger through multiplexers. However, for large number of sensors in a single string, routing of individual sensor cable to the top is a cumbersome, costlier affair. It limits the EAN-52M In-place inclinometer system with SDI-12 bus interface to SDI-12 compatible data logger number of sensors to be used in a single borehole and also increases the weight of the IPI assembly. Model EDI-52M system provides a solution, in which each in- place sensor is equipped with SDI-12 interface so that only a single 3 conductor bus cable needs to be threaded in a daisy chain fashion connecting each sensor to its next immediate neighbor and finally to the top of the borehole and directly to the data logger (without any multiplexer). SDI-12 bus cable from different IPI boreholes can also be connected to same data logger.

However, this includes some limitations on the total number of sensors or IPI strings being connected based on site conditions. Although in-place sensors with SDI-12 interface are a bit costlier, the savings in cable costs and the cost of the required multiplexers in the data logger reduces this increase to a large extent. For IPIs using a large number of sensors, SDI-12 equipped in-place sensors are a good choice as it will not be possible to accommodate a large number of individual signal cables inside the borehole.

3.3 Soil Moisture Probe

The 5TE was designed to measure the water content, electrical conductivity, and temperature of soil and growing media (**Fig. 4**). Using an oscillator running at 70 MHz, it measures the dielectric permittivity of soil to determine the water content. A thermistor in thermal contact with the sensor prongs provides the soil temperature, while the screws on the surface of the sensor form a two-sensor electrical array to measure electrical conductivity. The sensor uses an electromagnetic field to measure the dielectric permittivity of the surrounding medium. The sensor supplies a 70 MHz oscillating wave to the sensor prongs that charges according to the dielectric of the material. The stored charge is proportional to soil dielectric and soil volumetric water content. The 5TE microprocessor measures the charge and outputs a value of dielectric permittivity from the sensor. The 5TE sensor was designed to be used with Decagon's Em50, Em50R or the ProCheck handheld reader. The standard sensor (with 3.5 mm stereo connector) quickly connects to and is easily configured within a Decagon logger or selected in ProCheck. Decagon has tested its digital sensor successfully up to 1000 meters (3200 ft). This option eliminates the need for splicing the cable (a possible failure point).The 5TE can be inserted directly into growing media or soil.

Fig. 4 Soil moisture probe

3.4 Rain gauge

The tipping bucket rain gauge was attached with self-contained, battery-powered rainfall data collection and recording system (**Fig. 5**). The hobo data logger integrated into a tipping-bucket and the data automatically records up to 80" (1600mm) of rainfall data that can be used to determine the rainfall rates, times and duration. A time and date stamp was stored for each 0.01" tip events for detailed analysis.

Fig. 5. Hobo Rain gauge tipping bucket

4. Communication System

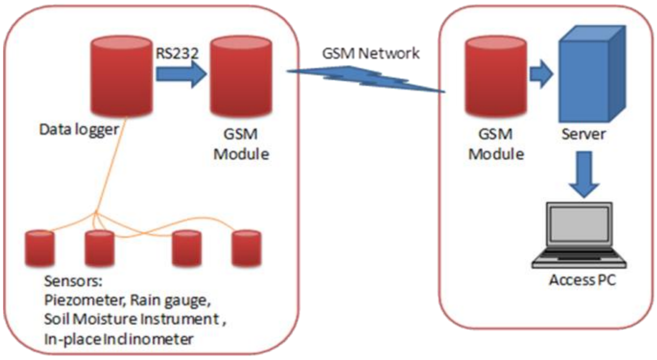


Fig. 6. GSM communication network

Figure 6 illustrates the GSM communication layout at the master logger tower. Data from sensors were collected and logged on a data logger. The data logger will transmit the data to the Petaling Jaya Office via GSM modem modules. The data received was then stored at the Petaling Jaya Office for further processing and analysis. The Campbell Scientific CR1000 was selected as the data logger for its broad range of measurement and control functions. Besides being rugged for extreme conditions and reliable for remote environments, the CR1000 was also robust for complex configurations.

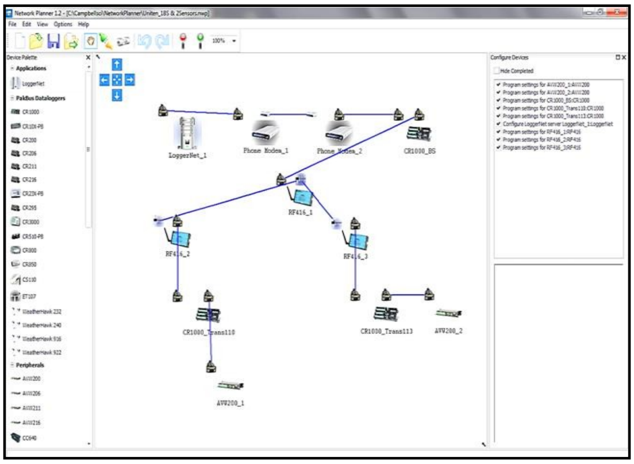
In this study, vibrating wire readout modules were needed to be connected since vibrating wire piezometers were used to measure the water table level. Hence, the Campbell Scientific AVW200 Vibrating Wire Spectrum Analyzers was connected to the RS-232 port. The module allows the CR1000 data loggers to measure up to 2 vibrating wire type sensors. A GSM modem is a wireless modem that works with a GSM wireless network. A wireless modem behaves like a dial-up modem. The main difference between them is that a dial-up modem sends and receives data through a fixed telephone line while a wireless modem sends and receives data through radio waves. The RF module operates at Radio

Frequency. For this study, the Campbell Scientific's RF416 module operates at 2.45 – 2.46 GHz using Frequency Hopping Spread Spectrum Radio technology. The module spreads narrowband data signal over wide band of frequencies and allows user-selectable pattern of frequency hopping. This results in communications that are immune to other RF sources such as cellular phone and pagers. To ensure uninterrupted operation of the communications system, and due to the remote location of the site, solar panels were employed and backed up with rechargeable lead acid batteries (**Fig. 7**).

Fig. 7. Communication pole at site

4. 1 Monitoring system

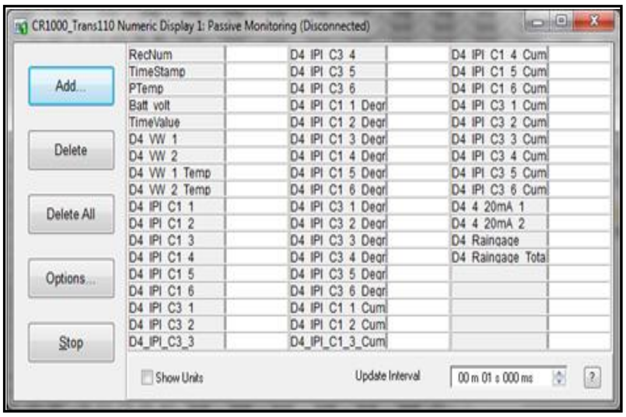
The server in the Petaling Jaya office was equipped with software that supports programming, communication and data retrieval from the CR1000 data loggers. **Figure 8** shows the screenshot of Network Architecture used in the project. The Campbell Scientific Loggernet allows for fast and user-friendly way of planning the network for the server to retrieve data from the remote sites' data loggers.



- ✓ Program settings for AVW200_1:AVW200
- ✓ Program settings for AVW200_2:AVW200
- ✓ Program settings for CR1000_BS:CR1000
- ✓ Program settings for CR1000_Trans110:CR1000
- ✓ Program settings for CR1000_Trans113:CR1000
- ✓ Configure LoggerNet server LoggerNet_1:LoggerNet
- ✓ Program settings for RF416_1:RF416
- ✓ Program settings for RF416_2:RF416
- ✓ Program settings for RF416_3:RF416

Fig. 8. Network Planning using Campbell Scientific Loggernet

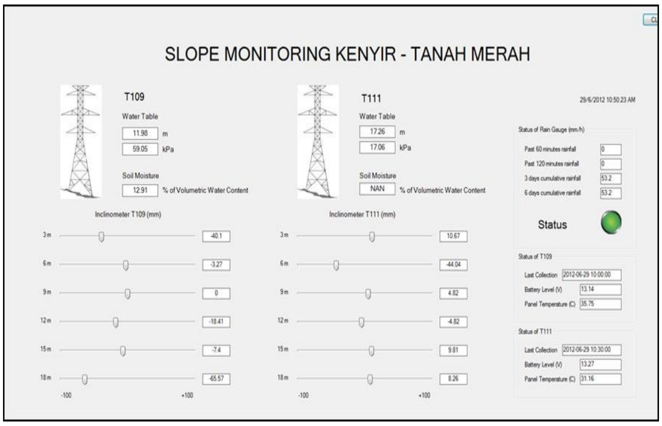
The software also consists of a server application to store received data and allows for user-customizable display screens to view data. Figure 9 and 10 show the numerical display and screenshot of the display screens. The latest data retrieved from the sites were displayed in the Numerical Display for further calculation and analysis. The analyzed data were then transferred to the display screen for better viewing experience, alarm triggering and graphical historical data to view the trend.



RecNum	D4 IPI C3 4	D4 IPI C1 4 Cum
TimeStamp	D4 IPI C3 5	D4 IPI C1 5 Cum
PTemp	D4 IPI C3 6	D4 IPI C1 6 Cum
Batt volt	D4 IPI C1 1 Degr	D4 IPI C3 1 Cum
TimeValue	D4 IPI C1 2 Degr	D4 IPI C3 2 Cum
D4 VW 1	D4 IPI C1 3 Degr	D4 IPI C3 3 Cum
D4 VW 2	D4 IPI C1 4 Degr	D4 IPI C3 4 Cum
D4 VW 1 Temp	D4 IPI C1 5 Degr	D4 IPI C3 5 Cum
D4 VW 2 Temp	D4 IPI C1 6 Degr	D4 IPI C3 6 Cum
D4 IPI C1 1	D4 IPI C3 1 Degr	D4 4 20mA 1
D4 IPI C1 2	D4 IPI C3 2 Degr	D4 4 20mA 2
D4 IPI C1 3	D4 IPI C3 3 Degr	D4 Raingage
D4 IPI C1 4	D4 IPI C3 4 Degr	D4 Raingage Total
D4 IPI C1 5	D4 IPI C3 5 Degr	
D4 IPI C1 6	D4 IPI C3 6 Degr	
D4 IPI C3 1	D4 IPI C1 1 Cum	
D4 IPI C3 2	D4 IPI C1 2 Cum	
D4_IPI_C3_3	D4_IPI_C1_3_Cum	

Update Interval: 00 m 01 s 000 ms

Fig. 9. Numerical Display of Retrieved Data



T109

Water Table: 11.98 m; 59.05 kPa

Soil Moisture: 12.91 % of Volumetric Water Content

T111

Water Table: 17.26 m; 17.06 kPa

Soil Moisture: NAN % of Volumetric Water Content

29/6/2012 10:50:23 AM

Inclinometer T109 (mm)		Inclinometer T111 (mm)	
3 m	-40.1	3 m	10.67
6 m	-3.27	6 m	-44.04
9 m	0	9 m	4.82
12 m	-18.41	12 m	-4.82
15 m	-7.4	15 m	9.81
18 m	-65.57	18 m	8.26

Status of Rain Gauge (mm/h)
Past 60 minutes rainfall: 0
Past 120 minutes rainfall: 0
3 days cumulative rainfall: 53.2
6 days cumulative rainfall: 53.2

Status of T109
Last Collection: 2012-06-29 10:00:00
Battery Level (V): 13.14
Panel Temperature (C): 35.75

Status of T111
Last Collection: 2012-06-29 10:30:00
Battery Level (V): 13.27
Panel Temperature (C): 31.16

Fig.10. Display screen for slope monitoring

4.2 Geotechnical Analysis Using Slope-W Software

Soil parameters used in Slope-W analysis were based on SI report conducted by SI contractor at Slope 1, as shown in **Table 1**. In this case, some parameters were assumed to be same, since the distance between these two towers was less than 400 meters. **Figure 11** and **12** show the illustration of instruments location plotted on Slope-W analysis results for Slope 1 and Slope 2 respectively.

Table 1. Parameters for Slope-W Analysis

Parameters	Unit weight of Soil, γ (kN/m^3)	Cohesion, c (Kpa)	Friction Angle, ϕ (degree)	Slope Angle, θ (degree)	Elevation (m)	Water Table (m)
Slope 1	17	2	30	24	240	18
Slope 2	17	2	30	62	355	17

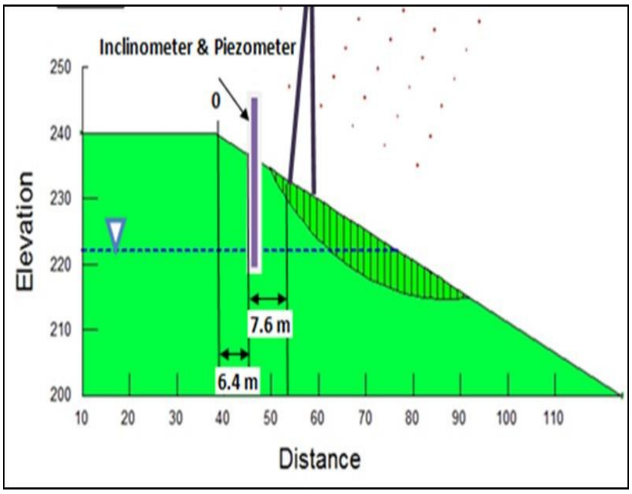


Fig. 11. Location of Piezometer and Inclinometer (Slope 1)

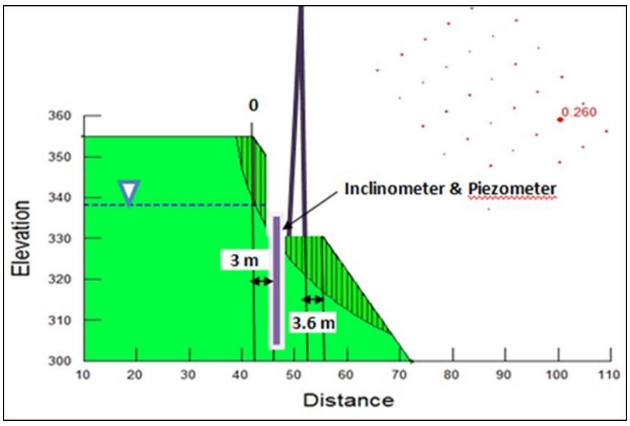


Fig. 12. Location of Piezometer and Inclinometer (Slope 2)

5. Results

In this study, the data collected at the site was transmitted to a server located at the Petaling Jaya office. Another computer set was also set up at the UNITEN office as a server. The data logger at Slope 1 and Slope 2 will record the data from every sensor in 30 minutes time interval. Both data loggers will send all the data collected to T113 using internal antenna.

T113 will send all data collected to the server in every 30 minutes. The server and T113 are directly connected using Celcom Modem to Modem data plan. **Figure 13** shows the loggernet system for CR1000 data logger installed in the server.

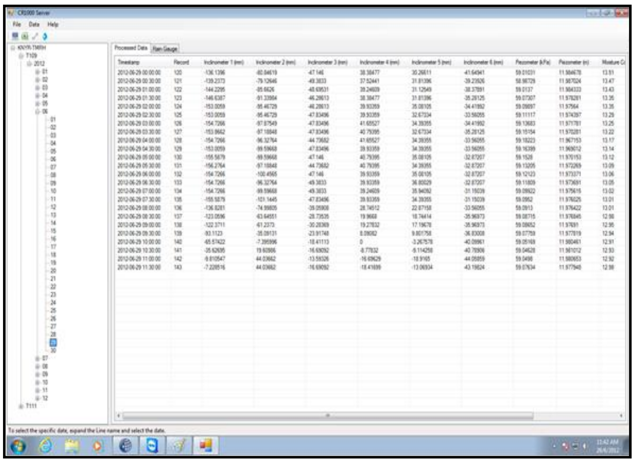


Fig. 13. CR1000 Server

The CR1000 server was programmed to directly connect with Microsoft Excel for data plotting. End users have to select the data to be plotted from the system as shown in **Fig. 14**.

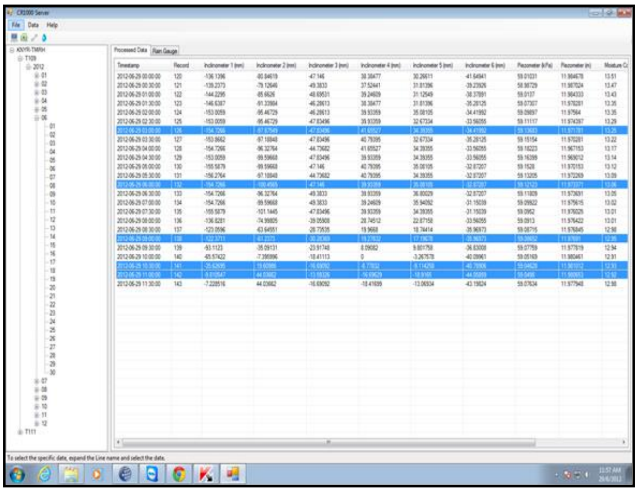
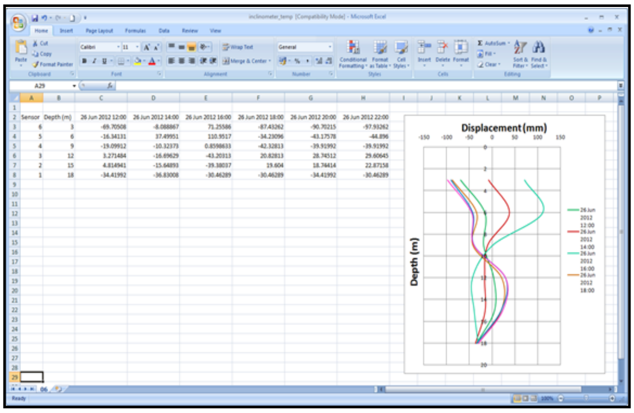


Fig. 14. Data selection on CR1000 Server

After data selection process, Microsoft Excel will automatically appear with plotted graph of the data selected. **Figure 15** shows the data collected by inclinometer for displacement, while **Fig. 16** shows the rain gauge and piezometer for rainfall intensity and water level.



Sensor	Depth (m)	26 Jun 2012 12:00	26 Jun 2012 14:00	26 Jun 2012 16:00	26 Jun 2012 18:00	26 Jun 2012 20:00	26 Jun 2012 22:00
6	3	-69.70508	-8.088867	71.25586	-87.43262	-90.70215	-97.93262
5	6	-16.34131	37.49951	110.9517	-34.23096	-43.17578	-44.896
4	9	-19.09912	-10.32373	0.8598633	-42.32813	-39.91992	-39.91992
3	12	3.271484	-16.69629	-43.20313	20.82813	28.74512	29.60645
2	15	4.814941	-15.64893	-39.38037	19.604	18.74414	22.87158
1	18	-34.41992	-36.83008	-30.46289	-30.46289	-34.41992	-30.46289

Fig. 15. Displacement Graph

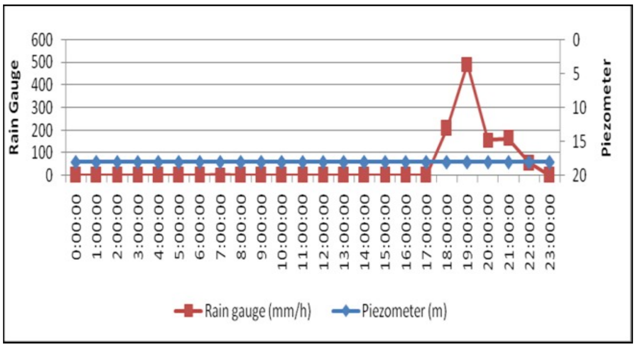
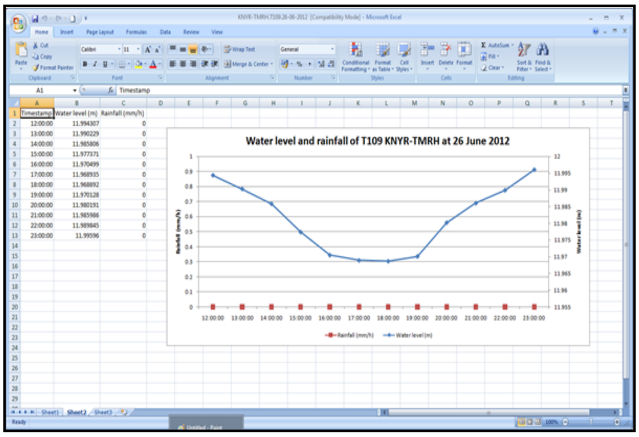


Fig. 18. Relationship between Rainfall and Ground Water Level (Slope 1)



Timestamp	Water level (m)	Rainfall (mm/h)
12:00:00	11.994307	0
13:00:00	11.990229	0
14:00:00	11.985806	0
15:00:00	11.977371	0
16:00:00	11.970499	0
17:00:00	11.968935	0
18:00:00	11.968692	0
19:00:00	11.970128	0
20:00:00	11.980191	0
21:00:00	11.985986	0
22:00:00	11.989845	0
23:00:00	11.99596	0

Fig. 16. Water Level and Rainfall Intensity Graph

Figure 17 shows cumulative rainfall at the study area. Based on the graph, total rainfall for 5 months monitoring was 4,000 mm. **Figure 18** and **19** show the piezometer reading (ground water level) at Slope 1 and Slope 2 during the highest rainfall recorded which was1085.2 mm/day on 15 November 2018. Even though the total rainfall was high, it did not cause any changes in ground water level recorded at both slopes. This activity was a sign that there was heavy surface run-off occurring on the slope. Heavy run-off will cause erosion and will lead to landslide after a certain time, depending on their soil behavior.

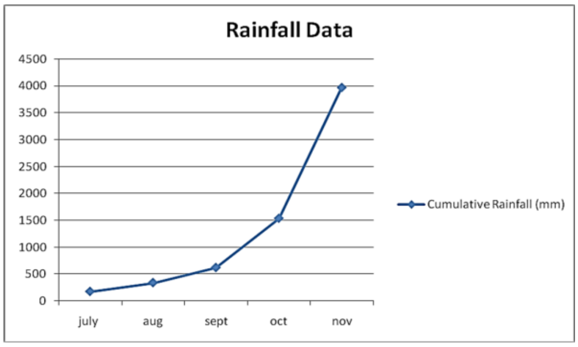


Fig. 17. Graph of rainfall data from July to November, 2018

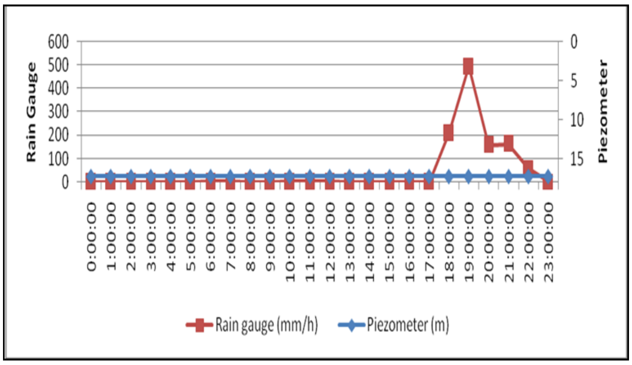


Fig. 19. Relationship between Rainfall and Ground Water Level (Slope 2)

Based on monitoring process from July to November 2018, this project found that the study area lies on residual granite soil, which is usually degrades into the bedrock and undergone chemical weathering process. Regarding to Malaysian Meteorological Department, east coast states are normally have maximum annual rainfall from November until January, while June and July are the driest month in most districts. Recorded data proof that July is falls in driest month since total rainfall is 173.2 mm, while heavy rainfall has begun on November since the total rainfall recorded is 2,435.6 mm for the month. Heavy rainfall does not cause any changes in ground water level at both study area. This phenomenon shows a sign of heavy surface run-off occur on the slope. Heavy run-off will cause erosion and this will lead to the occurrence of landslide.

6. Conclusions

The system network comprised of wireless remote monitoring which can help monitor infrastructure slopes especially in high risk areas and predict the stability of the slopes through the combination of geotechnical instruments and electronic sensors. This system was proven to be effective and can be implemented in the landslide risk management.

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