Jurnal
Teknologi

Full Paper

DEVELOPMENT OF SLOPE MONITORING DEVICE USING ACCELEROMETER

Article history
Received
18 January 2016
Received in revised form
8 March 2016
Accepted
18 March 2016

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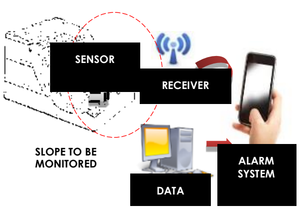
Graphical abstract



Abstract

There are many types of instruments that have been used for monitoring the high risk slopes as a precaution to prevent the loss of lives. Unfortunately, there is no such works of installation slope monitoring instrumentation as detectors and preventive actions before the slope failure. Automatic Wireless Accelerometer Monitoring System (AWAM) is a new device of monitoring system using accelerometer, introduced in this research. It is more efficient than conventional techniques and less expensive. The application and operation of this system does not interrupted by physical obstacles, different climate conditions, and the construction works at site. In addition, no contact is required since the accelerometers are installed on the slope. Consequently, geomorphology limitations are not considered as limitations of the system operation. This paper discusses the sensor database system by AWAM and shows the effectiveness of the device to monitor slope failures and act as a warning sign. It was presented in two parts; the first part consisted of the physical modelling calibration test from sensor database system (AWAM device) and from load cell test while the second part discussed on the numerical model simulated by using software (Slope/W and LimitState) and the data from vane shear test. The AWAM device can be used as a monitoring system to detect soil movements. However, accelerometer was able to give AWAM's readings if the device is moving in tilting modes.

Keywords: Monitoring device; slope deformation; sensor database system; physical modelling; numerical modelling

Abstrak

Terdapat banyak jenis alat yang telah digunakan untuk memantau cerun berisiko tinggi sebagai langkah pencegahan kehilangan nyawa. Akan tetapi, penyelidikan berkaitan pemantauan kegagalan cerun masih lagi di peringkat awal. Automatic Wireless Accelerometer Monitoring System (AWAM) adalah sistem pemantauan yang baru, menggunakan accelerometer, yang diperkenalkan dalam kajian ini. Sistem ini lebih cekap daripada teknik konvensional dan mengurangkan kos. Operasi sistem ini tidak akan diganggu oleh halangan fizikal, keadaan iklim yang berbeza dan kerja-kerja di tapak pembinaan. Di samping itu, tidak ada hubungan terus diperlukan kerana accelerometer ini dipasang pada cerun. Oleh itu, had geomorfologi tidak dianggap sebagai batasan operasi sistem. Kertas kerja ini membincangkan berkaitan sistem pangkalan data sensor oleh AWAM dan keberkesanannya dalam memantau kegagalan cerun serta bertindak sebagai tanda amaran awal sebelum kegagalan cerun berlaku. Ianya dibahagi kepada dua bahagian; bahagian pertama terdiri daripada ujian pemodelan fizikal bagi sistem pangkalan data sensor (peranti AWAM) dan dari ujian sel beban manakla bahagian kedua membincangkan pemodelan berangka dengan menggunakan perisian (Slope / W dan LimitState) dan data dari ujian kekuatan ricih. AWAM boleh digunakan sebagai satu sistem pemantauan untuk mengesan pergerakan tanah. Walau bagaimanapun, accelerometer hanya dapat memberi bacaan AWAM jika peranti bergerak dalam mod serong.

Kata kunci: Sistem pemantauan; kegagalan cerun; sistem pangkalan data sensor; model fizikal; model berangka

1.0 INTRODUCTION

Slope stability is a major problem in geotechnical engineering where disasters involving loss of life and property can occur [1]. Many fatalities have occurred due to slope failure [2]. Even when there is no injury, there is a high cost due to construction delay, building damages, lost production and often damaged equipment. Many cases have been recorded as landslides in Malaysia that made a big impact to the society. One adverse events that is still remembered until today is the tragedy of Highland Tower on December 11, 1993 in Park Hillview, Ulu Klang, Selangor, Malaysia [3]. The incident has claimed the lives of 48 citizens when one of the apartment building collapsed due to slope failure. This failure is caused by the rapid development in the hilly area known as Bukit Antarabangsa Development Project. Factor of water from surrounding development and monsoon rains at the end of the year is the major cause of this catastrophe. After the tragedy, a series of landslides occurred around the area in which it also has claimed many lives.

It has been reported that based on the 49 individual slope failure cases investigated, 60 % of the failure is caused by man-made slopes [4]. This is due to the weakness design, for instance the design exceed the maximum angle of slope construction, underestimating rainfall condition and lack of maintenance. In addition; poor workmanship, quality of materials and lack of site supervision contributed to the total cases of landslides during constructions work.

Some typical signs of landslide danger could be foretold such as appearance of water overflowing near the toe / base surface of a slope or retaining walls (Flooding of water in hilly areas). It shows that the water is not flowing along a proper channel, and instead pools in unexpected areas. It also indicates that water is seeping into the slope and flowing out at the base (seepage problems). Sudden change in color (from clear to muddy) of water flowing from slopes or retaining walls is also an indicator of slope failure. Fences, trees and retaining structures on slopes are going to tilt or move. It shows that there is ground movement on the slopes. Find a new large cracks and ground settlement occur in slopes, retaining walls or along road pavements. It is a horizontal crack that appears at the top of the slope where parts of the soil and rock layer break away from the main slope.

The risk of these tragedies to repeat again could be minimized if the monitoring system of the slope failure was implemented. The previous early warning methods are implemented by using rain gauges and surface monitoring devices as the instrumentations. It is difficult to determine the effectiveness of these tools as they monitor only the surface of potential failed slopes. As of today, surveying on slope movement (monitoring system) can be performed by several methods. A common technique to determine slope stability is to monitor the small precursory movements such as deformations, which occur prior to collapse. There are many types of instruments that have been used for monitoring the slopes at high risk. Instruments such as inclinometer, theodolite, electronic distance meter, or tiltmeter [5]. Inclinometer is used to monitor the lateral earth movements (deformation) especially in landslide area and embankment. They are also used to monitor the deflection of retaining wall and piles under load. A number of studies are previously done to create alternatives of slope monitoring systems.

Ding proposed an automatic monitoring of slope deformation using geotechnical instruments equipped with self-contained power supply system consists of solar power and rechargeable batteries, data logger and alarm system at the slope site. Various commercial sensors (extensometer, tilt meter, strain and stress gauge, and piezometer) were used to provide the deformation data. All the site information will then be transferred to central computer software by using a wireless system [6]. Bozzano [7] conducted a continuous monitoring on slope structure for 23 months using an integrated platform with a ground-based SAR interferometer (GBInSAR), a weather station, and an automatic camera. This method could provide the opportunity to analyze the response of an unstable slope to the different phases of work. The deformational behaviour of both the natural slope and the man-made structures was recorded and interpreted in relation to the working stages and the rainfall conditions during the whole monitoring period. Khan *et al.* measured hill-slope movement of the Gunung Pass, Cameron Highland, Pahang, Malaysia slope site using theodolite and collection of rainfall data. Prisms and theodolite were employed to measure the ground displacement [8]. The other method is based on remote sensing techniques such as Synthetic Aperture Radar (SAR) data with differential information, while some are based on Global Positioning System (GPS) [9-11].

However, current practice in Malaysia and the implementation of slope monitoring work is often neglected as the cost and maintenance of instrumentation is high. Conventional instrumentation for monitoring deformation have a limitations such as a factor of geomorphology at the area, physical obstacles, different climate conditions, and the on-going construction work on the site. These limitations will cause high price of the equipment to purchase. Besides that, the transmission of the data is a main problem with addition to the absence of electricity supply since most slopes are isolated and away from the power source. This method also needs a team to supervise, monitor and take a readings manually.

This research is intended to benefit the monitoring instrumentation for slope engineering. The instrumentation used is based on monitoring of deformation that occurs to the subject which is focusing on slope. The objectives for this study are to propose the concept of automatic and wireless system for monitoring purposes. It is a new product of slope monitoring system with less cost, user friendly and more effective. The product is named as Automatic Wireless Accelerometer Monitoring System (AWAM). A small-scale physical laboratory testing was scheduled to calibrate the system and detect the signal of failure. After that, the performance of the system would be put to the test in a full scale test.

Automatic wireless accelerometer monitoring (AWAM) system will implement an early warning system that can be achieved by using real-time data that is programmed to send a signal when it reaches a critical value and eventually foresee the risk of a potential slope failure.

2.0 METHOD AND MATERIAL

2.1 Automatic Wireless Accelerometer Monitoring System (Awam) Operation

Automatic Wireless Accelerometer Monitoring System (AWAM) is a new product proposed in this study for slope monitoring. The system is intended for monitoring the deformation automatically by using an accelerometer and it does not require human input to function after initial setup. The accelerometer is a device that measures proper acceleration. Consequently this device can be used to provide the required data by measuring the motion, vibration, and speed of any movement in slope body. The sensors can obtain better readings although there are obstacles and a climate condition occurs. Transfer information / data by using this device are wireless and the power supply are generating from the solar energy. The cost of this device is also cheaper than the existing device in the market.

The distance between the sensor and the receiver of the device within 1 km and allows monitoring of each type of movement that affects the slope. Data from the receiver will be analyzed by using software that has been designed to suit the function of this device. Wireless LAN (WLAN) and mobile communications (GSM / GPRS / UMTS Network) is a communication tools for data streaming between measuring devices and the data acquisition software (Figure 1).

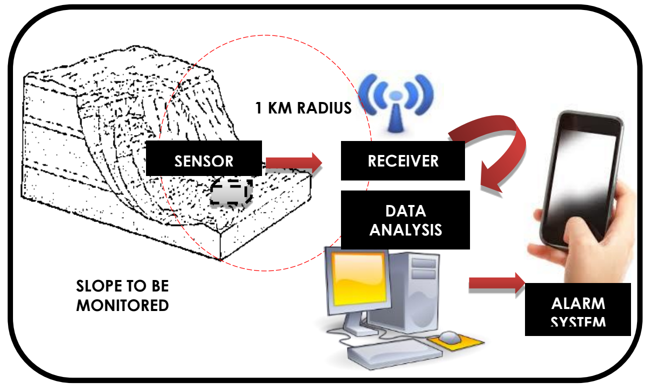


Figure 1 Diagram process of AWAM system

Data acquisition and analysis software are including data management, analysis, and alarm systems. Data acquisition and analysis devices include personal computer or laptop, and smartphone. These devices are used to receive the required data from data provider accelerometers through communication provider and allow the data acquisition and analysis software to work with data. Personal computer or laptop is used as data acquisition and analysis device and smartphone is utilized as alarm device. The software is very important in monitoring system for acquiring data from an accelerometer, a calculation of the mean values of measurements, recording the results, reflect the change and the person responsible should concern the critical signal failure is detected (the limit deformation before failure).

With this system, it is expected that the critical slope monitoring can be given that the price offered is lower than the existing tools with improved energy efficiency and the transmission and acquisition of more accurate data and fast.

2.2 Geotechnical Modelling

This study consists of physical modeling and numerical modeling. The physical modeling obtains an appropriate variable factor for the AWAM system. One (1) soil sample was prepared and the parameters of the sample were obtained by using vane shear test. The tests were carried out with the concept of load increment until failure.

2.2.1 Device Calibration

The purpose of calibration is to measure any changes of movement will affect the result of AWAM system by monitoring through Sensor Database System (Figure 2). This device can be used to provide the required data by measuring the motion, vibration, and speed of any movement in slope body. The test will be set up as show in Figure 2. The AWAM device was moved slowly and the data from both Linear Variable

Differential Transducer (LVDT) and Sensor Database System were taken and recorded.

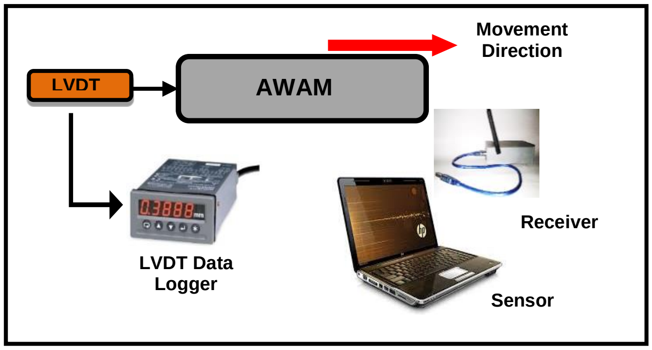


Figure 2 Device calibration set up

Table 1 Summary result of calibration test

Axis	Slope Gradient (m value from graph)			
	Test 1	Test 2	Test 3	Test 4
X	-0.2494	-0.4594	-0.2601	-1.1062
Y	-0.5323	-0.1507	-0.111	12.622
Z	0.9803	-0.1157	0.9281	-1.0653

2.2.2 *Physical Modelling*

The construction of slope was carried out in two main steps including filling and compacting. The designed frame and geometry of the slope as show in Figure 3.

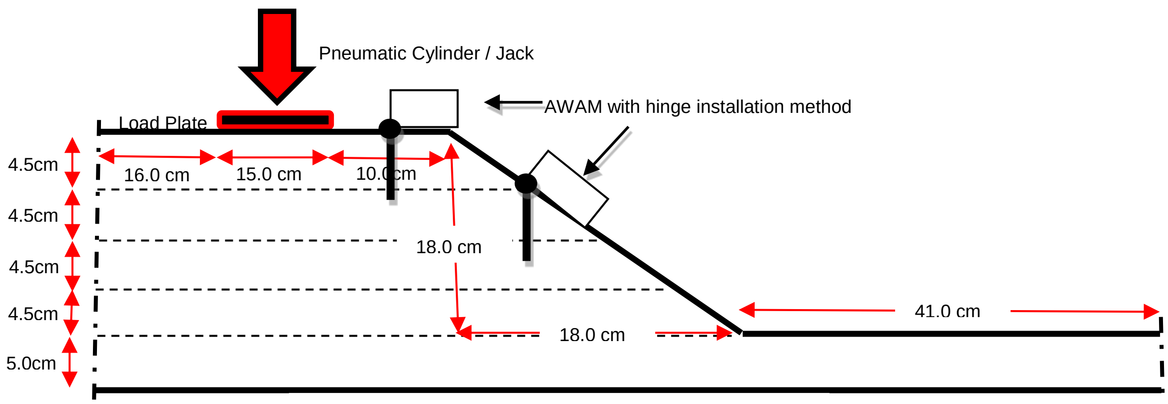


Figure 3 Proposed geometry for slope model

Calibration test were done to determine the correlation between data of LVDT and Sensor Database System (AWAM System). In this research, 4 tests were conducted in varied direction. Three (3) test were done in x direction (Test 1, Test 2 & Test 3) and one (1) more test were done in y direction (Test 4). The calibrations were performed to obtain readings before and after movements of the sensor in the x-axis.

Based on the result from Table 1 of calibration tests carried out, it shows that there is no correlation between the data of LVDT and sensor database system. The slope gradient from the graph (m value) is not consistent. When the position of the device changed, it did not yield any significant changes to the reading from sensor database system. From the results and observation, it can be concluded that the device was not able to provide any reading on changes of same plane position. Accelerometer will gives AWAM device the readings if the device is moving in a tilting mode. As a result from the test, the device should be modified in order to give tilt effect to the accelerometer and the device. One part of the device must be fixed in order to apply the effects of tilt during ground movements that will cause slope failure. Some modification to the device had been done to give a tilt effects.

In order to maintain the intended moisture content, density, and homogeneity of the soil, the compaction of soil was performed in five layers. 5.0 cm for the first layer (Base Layer) and the remaining layer will be constructed to 4.5 cm height. The upper surface of each layer was scratched before placing the next layer to keep the connection of layers and avoid inhomogeneity in the model [12].

After compaction of all layers into the designated frame, the designed gradient of the slope was created by carefully removing extra volume of the soil from the model. The proposed gradient for this model is 1:1 geometry. The location of AWAM device will be on top of slope (Device 1; X1, Y1 and Z1) and the second one will be on slope (Device 2; X2, Y2 and Z2). Finally, the load plate was placed in its designated location and the box of the model was relocated to the test area under the pneumatic cylinder. The LVDTs were installed on the frame attach with pneumatic cylinder to record the vertical displacement of the soil. Data acquisition systems of the test included a data logger to record and print the vertical load as well as vertical displacement in 15 s interval. Simultaneously, AWAM device will be set up and record the data in 5 s interval.

2.2.3 Numerical Modelling

Numerical modeling is a computer simulation by using certain software to reproduce the behavior of the system under study. For this study, the software Geo-Slope (Slope / W) and Limitstate were used to make comparisons between physical modeling and numerical modeling. Before the analysis was done by software, several parameters were identified from the model. Compaction test (Moisture content) and vane shear test (shear strength) were conducted to ensure the homogeneity of the soil model.

From the test result, it shows that the soil is homogeneous. The moisture content is in the range between 20 to 22 percent and the shear strength value for analysis is 32 kPa. For this analysis, the assumption for unit weight is 18 kN/m^3. The properties of the slope and slope material were inserted into the model and the vertical load was set equal to the failure load of the tested model.

3.0 RESULTS AND DISCUSSION

3.1 Physical Modelling

The result from LVDT and data logger was used to record the changes of soil in distance (mm) and the Load Cell was used to measure the applied load. Figure 4 shows the relationship between the stress on the soil material and the corresponding strain (due to deformation) as recorded by LVDT.

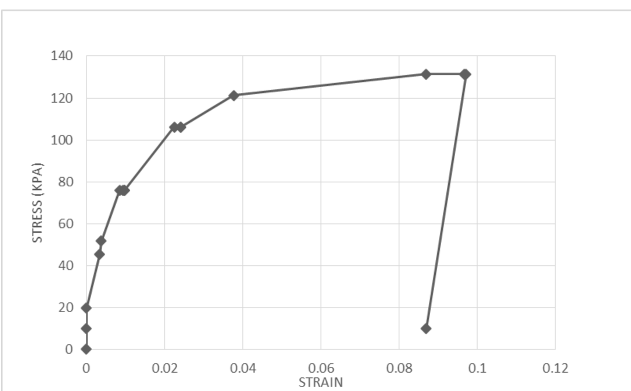


Figure 4 Relationship between stress and strain

The graph shows that the normal curve of applied vertical load versus vertical displacement as obtained from data logger. It shows that the plotted graph is similar to the stress vs. strain graph of soil behavior obtained by Kalatehjari [12]. As a result, at the time of 15:36:00, the slope failed when the load reaches the number greater than 131.4 kPa. In addition, it can be concluded that the mechanism of soil behavior is a sudden failure.

The result from sensor database system by AWAM device was recorded any data and changes due to the tilting effect with 5 s time interval to detect slope failure. From the results obtained, X1-axis shows a small changes but does not affect the overall result as shown in Figure 5. The device 1 @ Y1-axis had detected a major change of soil structure starting from time 15:35:55 as can be seen in Figure 6. Other axis does not show any sudden changes from the data obtained (Figure 7).

After 10s (15:36:05), device 2 @ Y2-axis and Z2-axis started to detect the tilting effect (Figures 9 and 10). 5s after that (15:36:10), X2-axis also made some changes due to the soil movements (Figure 8).

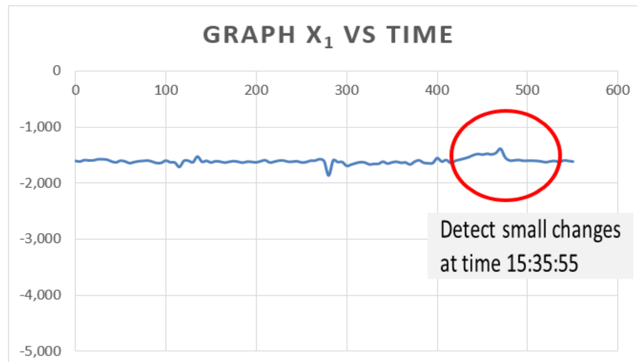


Figure 5 Graph X_1 versus time interval

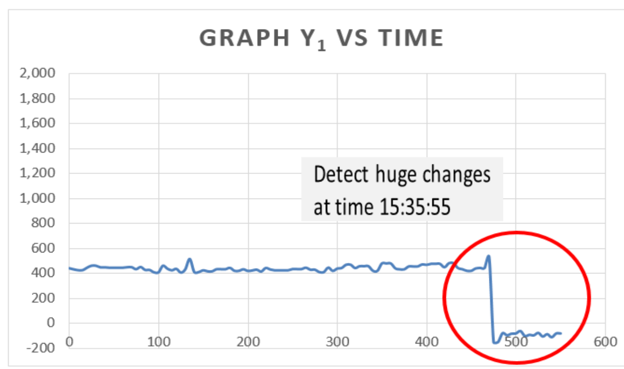


Figure 6 Graph Y_1 versus time interval

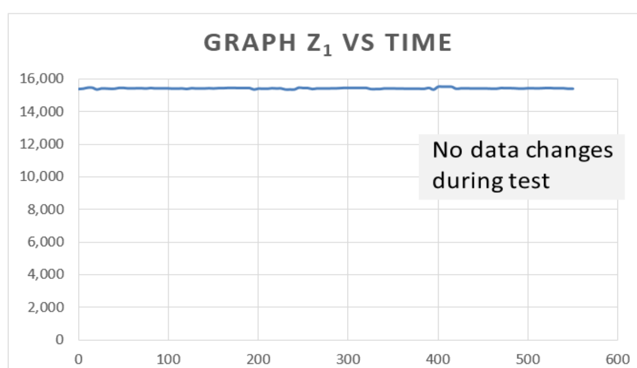


Figure 7 Graph Z_1 versus time interval

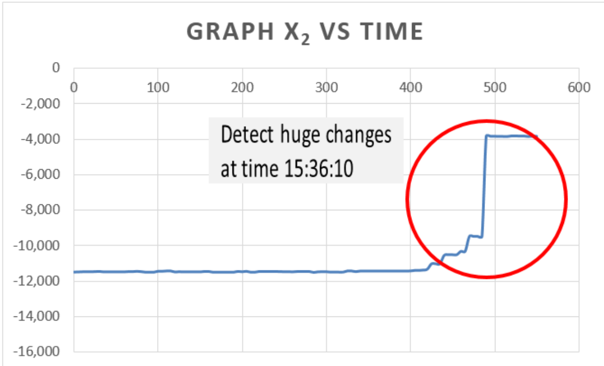


Figure 8 Graph X_2 versus time interval

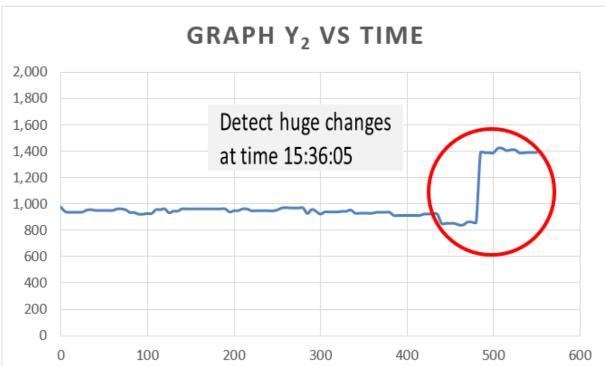


Figure 9 Graph Y_2 versus time interval

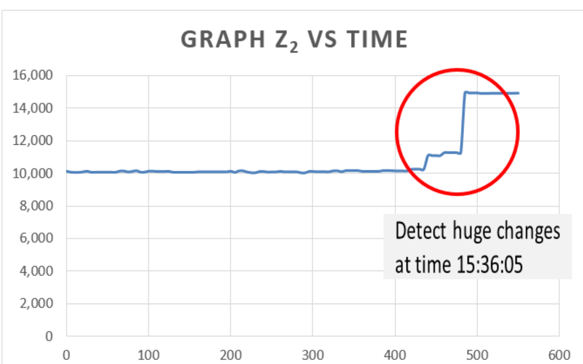


Figure 10 Graph Z_2 versus time interval

By comparing the result from data logger and sensor database system, it shows some correlation between both results. The device had detected early signs of movement that occurred before the slope failure. With this device due to its tilting effect, it can demonstrate the slope failure by detecting slight movement of the soil. From the result, it is concluded that it is more effective to locate the device at the top of slope (location of device 1) than on the slope itself (location of device 2). This is because the device 1 gave early warning sign before the device 2 detected the failure (10 second delay). From the observation, due of the sudden failure and the geometry of the device are not suitable for the small model, the time period between warning sign from AWAM device and slope failure occurred is quite close.

3.2 Numerical Modelling

Figure 11 shows the result obtained from LimitState software. The same size and geometry from the model was used in this analysis. FOS for the model by using this software is 1.05.

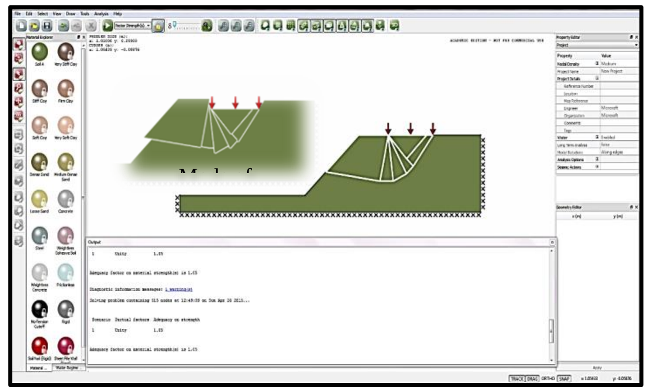


Figure 11 LimitState analysis result (FOS = 1.05)

Figure 12 shows the result of surface failure of the slope from the analysis using Slope/W. In this case, analysis was done by considering the Buckingham π-Theorem. By fixing the value of shear strength, the unit weight are reduced by n=100 to be 0.18 kN/m^3. The factor of safety obtained from the analysis is 1.033 which is slightly higher than 1.0 at failure point.

From both analyses, it has been identified that the result is consistent. The factor of safety value from LimitState software is about the same as the result of Slope/W. The value is approaching the failure point at FOS = 1.0, it is verified that the loading applied on the slopes causing soil movement and lead to failure. From the result, it can be concluded that this device is able to detect the soil movement as well as monitoring the slope before it fails. The laboratory model constructed are able to demonstrate the effectiveness of the AWAM device and hopefully in actual environment it can provide better result and raise awareness of slope failures.

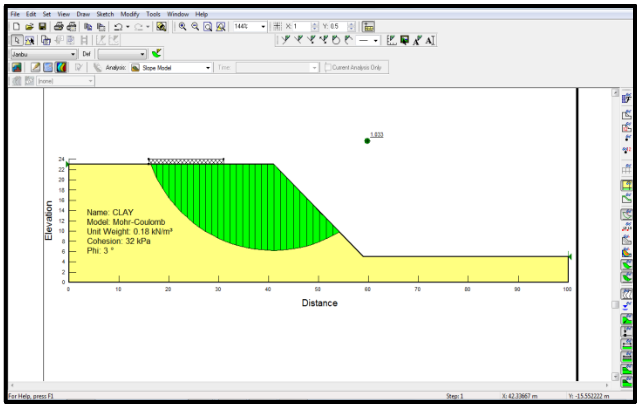


Figure 12 Slope/W analysis result (FOS = 1.033)

4.0 CONCLUSION

The objectives for this research had been successfully achieved. The concept of automatic and wireless system for monitoring device was introduced by using accelerometer. Based on the results and analysis carried out, it can be conclude that the AWAM device which was integrated with accelerometer cannot be used to detect any movement and cannot provide readings of the changes at the same plane position. Accelerometer was able to give AWAM's readings if the device is moving in tilting modes. The modification done to the device causing a tilting effect and making the device works as intended. The AWAM device can be used as a monitoring system to detect soil movements. It can also act as a warning sign system before slope failure. The outcomes from the AWAM devices are varied depending on the location placement. It is more effective to locate the device at the top of the slope than on the slope surface itself. The reason is because the device 1 (on the top of the slope) gives early warning sign before the device 2 (on the slope surface) detects the failure.

Result from soil properties of the model shows that the slope structure is in homogeneity. It also verified the loading applied on the slopes that caused slope failure by using the software analysis. It shows that the model in laboratory can prove the effectiveness of the AWAM device but in real condition, it will give a better result and awareness of slope failure.

Acknowledgement

Appreciation goes to the Ministry of Higher Education, Malaysia for FRGS grant number 4F658.

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