Monitoring of Landslide in Heavy Rainfall Areas Using Low-Cost Microcontrollers

K. S. Beena, O. Varun Menon, and P. J. Rooma

1 Introduction

1.1 General

Among natural hazards, landslides occur virtually in every country in the world. Globally, it causes approximately 10,000 deaths a year along with property damage [1]. These slope failures have become a common geotechnical problem and are most common in many countries such as Hong Kong, Italy, Singapore, and India. In India, the Nilgiris region has frequently been confronted with the occurrence of slope failures and landslides. It poses a serious threat to human life and structures built in proximity. Early landslide warning is largely phenomenological, relying on surface measurements of displacements over time [2]. Landslides can be initiated in slopes already on the verge of movement by rainfall, snowmelt, changes in water level, stream erosion, and changes in groundwater, earthquakes, volcanic activity, disturbance by human activities, or any combination of these factors. Among these, rainfall is one of the most effective factors.

Rainfall-induced slope failures are due to a complex interaction between hydrological and geotechnical processes. Parameters of the slope that affect the stability of slope are slope angle, density of soil and its moisture content. Landslides usually occur during wet periods and the slope failures are induced by rainfall infiltration. During any rainfall period, negative pore-water pressures in an unsaturated soil slope are gradually reduced by rainfall infiltration and positive pressures start building up. This process may cause instability to soil slope. Rainfall intensity and duration play an important role in the extent and manner of slope failure. High-intensity short duration rainfall can easily trigger landslides.

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Modeling of scaled embankments and monitoring of water contents within the soil, allow us to understand and to correlate the response of the soils due to the rainfall infiltration in the field. By conducting scaled model studies in the past, it has been inferred that the slope failure was induced by increasing the degree of saturation within the slope through seepage from the upslope section or by direct rainfall [3]. Water infiltration alone was not sufficient to induce instability. Rather, generation of pore-water pressure and increase in saturation ratios associated with the rise in the water level were necessary to create highly unstable zones. When most parts of the soil slope are almost fully saturated particularly those in the potential failure surface, a retrogressive type of failure is observed. The studies also demonstrated the possibility of predicting slope failure initiation by monitoring the changes in soil moisture content within the slope.

This clearly directs us to embark on a study with the help of monitoring devices to understand the phenomenon of landslide in a more perspective manner. In the past, such studies have been conducted [4] and it involves the installation of a real-time monitoring system to observe the physical property changes in soils in a valley during rainfall events. This monitoring included the measurement of volumetric water content, which was compared with the results of laboratory flume tests to identify landslide indicators in the soils. The results showed that there is a directly proportional relationship between the effective cumulative rainfall and the gradient of volumetric water content per unit time (t/t_{max}). Laboratory results showed that a high amount of rainfall and a high gradient of volumetric water content could induce slope failure.

This study involves the measurement of moisture content using sensors placed at various locations of the slope, thus in turn can be used as an early warning system for landslides. The effect of rainfall intensity on soils with different slope angles was investigated at constant density.

2 Laboratory Experiments

2.1 General

Many researchers work on theory, analysis, numerical simulation, and model tests. The rainfall simulator which can reproduce the rainfall intensity, drop size, drop energy, spatial and temporal distribution for the model test of landslide is very important [5]. Fabrication of a rainfall simulator was the first objective before conducting the model studies. With the available resources on the premises, we were able to assemble the simulator as seen in Fig. 1.

The study has been conducted with varying slopes of 30, 45, and 60° at a moisture content of 7.5% and filled by keeping 90% maximum dry density (1.53 g/cc). The water content is obtained from conducting a standard proctor test and interpolating the corresponding dry density. The main purpose of this study is to identify the point

Fig. 1 Rainfall simulator

at which the landslide triggers and let that point be the threshold in the upcoming proposal involving the early warning systems.

The soil has been collected from the geotechnical laboratory and basic properties have been found to maintain constant density throughout each iteration. The intensity of rainfall can be controlled by adjusting the inlet valves and the measurement is taken using a measuring jar.

2.2 Material Characteristics

The model studies have been conducted [7] with the facility available at Geotechnical laboratory, Cochin University of Science and Technology using red lateritic soil having the following material properties as given in Table 1. The soil comes under the classification of ML (low plasticity silt).

Table 1 Material properties

Property type	Value	Unit
Specific gravity	2.76	
Liquid limit	61	%
Plastic limit	28.30	%
Maximum dry density	1.70	g/cc
Optimum moisture content	14	%
D10	0.23	Mm
D30	0.70	Mm
D60	1.50	Mm
Cc	6.52	
Cu	1.42	
Soil classification	ML	

2.3 Sensor Characteristics

The experiments are conducted with the open-source platform called Arduino. To be precise, we have used the ATmega328P micro-controller-based Arduino Uno board for experimentation. This board can carry out small-scale processing with 32 kb internal memory. It can read both Analogue and digital data. We have used a SEN0114 analog output soil moisture sensor in locations A0 to A5 as given in Fig. 2. Figure 2 also consists of the image of the SEN0114.

Figure 2 gives the sensor locations corresponding to the 30° slope and there can be slight variations in the sensor locations for slopes of 45 and 60°. The sensors used in each location are the same for every individual testing to avoid any calibration errors.

Calibration of the sensors is the next important step in this study so that the medium between the man and the machine will become clearer to interpret. The ability of a system to communicate with the scientist is very important in the case of experimental study, so we must understand how the microcontroller responds with

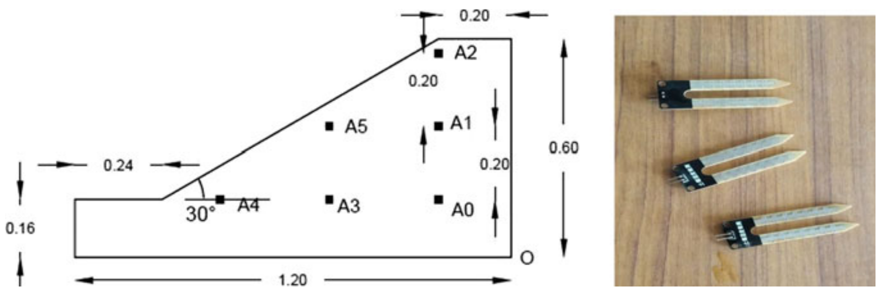

Fig. 2 Locations of the sensors in the model and the SEN0114 soil moisture sensor

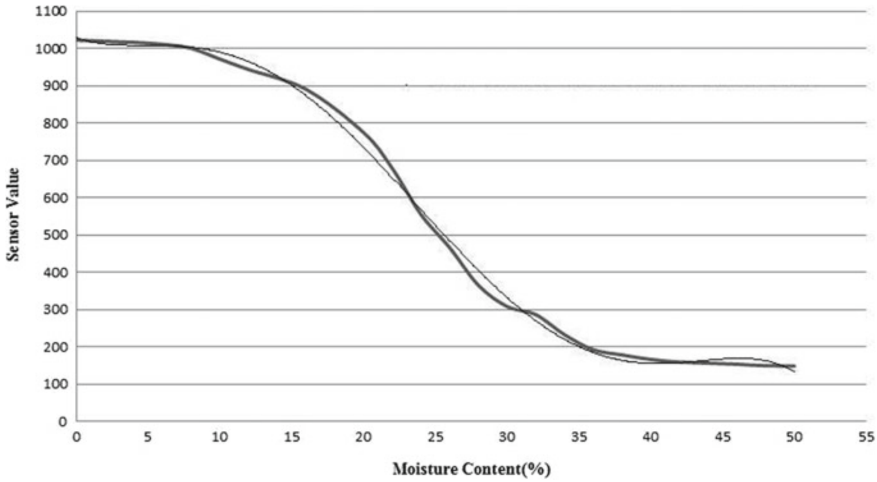

Fig. 3 Calibration chart of the SEN0114 sensors

the change in water content in the soil. For that, a dummy test has been conducted by filling 100 g of soil in a bowl and the water content has been changed by adding a known quantity of water from a dry state to the point up to which the sensor gives data. Figure 3 is the representative graph of the sensitivity of SEN0114 type moisture sensors.

This chart has been further used to relate between analog values of the sensors during experiments and the real-world moisture content of the soil.

By analyzing the data given in Fig. 3, it can also be observed that the sensors can be significantly sensitive during the regions of 10–40% moisture content in this soil.

According to the result of the experiment, moisture sensors located at different position shows a significant change in the values during the simulation of rainfall. These changes were in response to the infiltration of rainwater. The stage of increased moisture content was very prominent near the slope surface and with shallower sensors. The surface sensors respond earlier than those deeper within the slope profile.

Further to this, the sensors located closer to the slope recorded an increase in moisture content. In the next stage, the sensors placed at deeper depth show the increase in moisture content. Finally, the bottom sensors near the heel show higher moisture content than the top sensors because of the accumulation of water from top to bottom. But there is a slight variation in the duration of the sudden increase in moisture content at some locations of the slope due to the topographical characteristics (slope angle). The soil condition in the model slope is gradually changed from an unsaturated condition to a saturated condition by the infiltration of rainfall. When the water content reaches the maximum value in the saturated condition, it maintains the maximum value uniformly with further rainfall simulation. The water content at which embankment soil becomes fully saturated is theoretically obtained as 30% for a 90% relative density of this soil. A slope failure was observed for 60^0 slopes under high-intensity rainfall conditions as seen in Fig. 4. In other slopes (i.e., 30^0 and 45^0) no failures were observed during the experimental study.

As per Fig. 5, the locations of the sensors in the failed model can be identified. The sensors are given in various locations to study the influence of water in the soil body with varying depth. The sensors A2, A4, and A5 are the most critical ones in the slope. The failure has occurred at the 600-s mark from the start of the simulation of the rain. The rainfall intensity was later calculated to be 48 mm/hr. Also, Fig. 6 shows the point of failure in each scenario, from this data we can come to an understanding that the limit of allowable water content just before failure can be set to 27 to 35% for this soil.

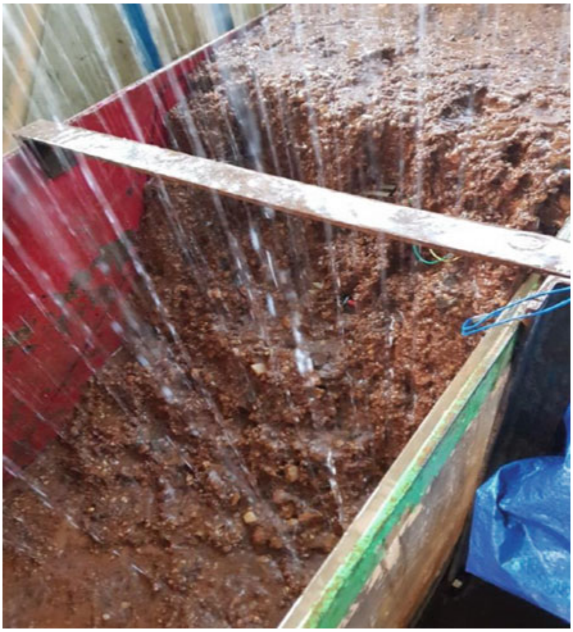

Fig. 4 Failure of 60° slope model

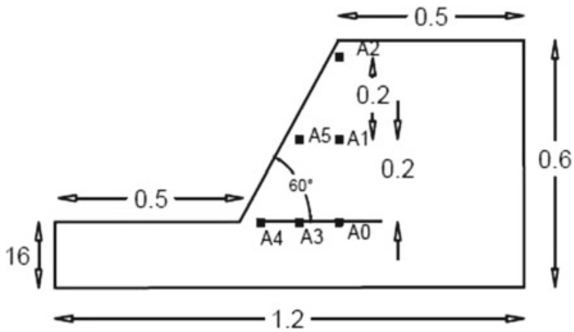

Fig. 5 Locations of the sensors (not to scale)

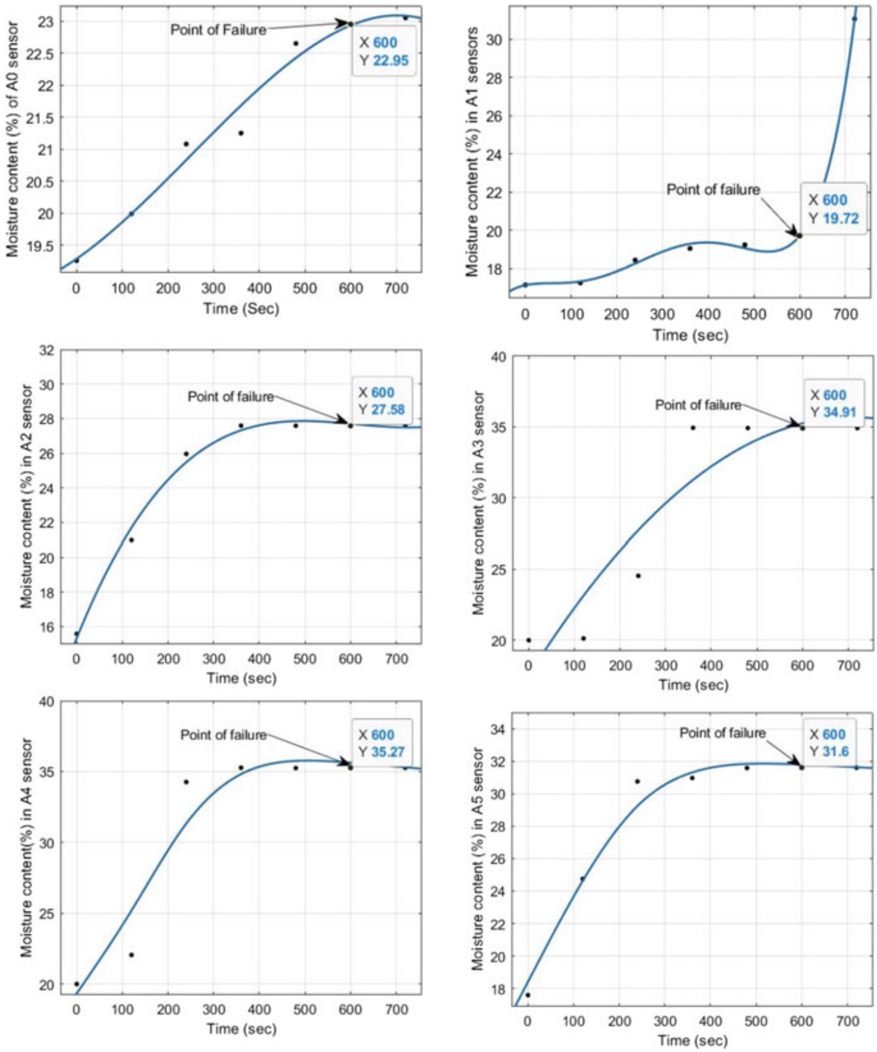

Fig. 6 Moisture content versus time graph of each sensor in the 60° slope model

The locations A2, A4, and A5 are very critical for the current study as this is closer to the upper layer soil. Landslide is a phenomenon, in which the upper layer of soil tends to lose its friction with the layer below it, causing large mass movement. The sensors at A0, A1, and A3 provide us with the moisture content deep under the top of the soil, these reading can be used for other studies like soil internal erosion. The current scope of study only focuses on landslides and early warning system design.

The data obtained was tabulated in MATLAB and Fig. 6 is plotted. This contains moisture content measured by each SEN0114 sensor versus time in seconds data.

The major implications of this graph in this study are the moisture content at the point of failure and the time it takes to reach this point. The development of an early warning system depends on these values as the point of failure data is given in the programming of the micro-controllers. There should be a suitable factor of safety that has to be considered to allow enough time to order an evacuation.

If the sensors read this threshold value and the rainfall intensity is greater than the one in the model study case, the failure is imminent. This is considered without taking the man-made factors that may accelerate the failure process. For that further investigative study is recommended.

From the obtained data, A2, A4, and A5 show similar values. The sensors reach the failure moisture content earlier than the failure point. It means there is a time gap between the failure point and the first presence of that moisture content value in the sensors. These can be easily spotted in Fig. 6 and the time gap can be approximated. This is a very useful data, and further study on unsaturated soil regions is recommended on why this delay occurred to lose the strength of the soil.

Figure 6 depicts the moisture content versus time graph plotted taking value every 120 s time interval. The lowest value measured by the sensor at the failure point as per the Fig. 6 is 19% although this value is of a deeper stratum than the surface soil, hence the values obtained from A2, A4, and A5 are only considered for the present study. From the data obtained as above, we are considering to give a factor of safety of 2 for this current soil and take 13.5% (half of 27% at which the failure triggered) as the threshold for our early warning. Because as per Fig. 6, the progression toward the failure point moisture content seems to be very rapid. The sensors also show that the value has already been reached at an earlier point of time and it tends to prolong that same moisture content for more than 300 s before failure. In the further sections of the study, we are only considering 13.5% moisture content as the threshold.

3 Future Developments Recommended

3.1 General

ESP32 belonging to Espressif systems is a multipurpose microcontroller with 2.4 GHz Wi-Fi and Bluetooth capability, it shows robustness and versatility with a wide variety of applications [6]. There are many models available in the market at an affordable price, from which we have selected ESP32-WROOM-32 as seen in Fig. 7. Using Microsoft Visual Studio Code software, we can code it to perform various tasks. The ability of ESP32 to access the internet plays a key role in the development of an early warning system. ESP 32 can be powered with a 9 V battery or AC to DC adapters.

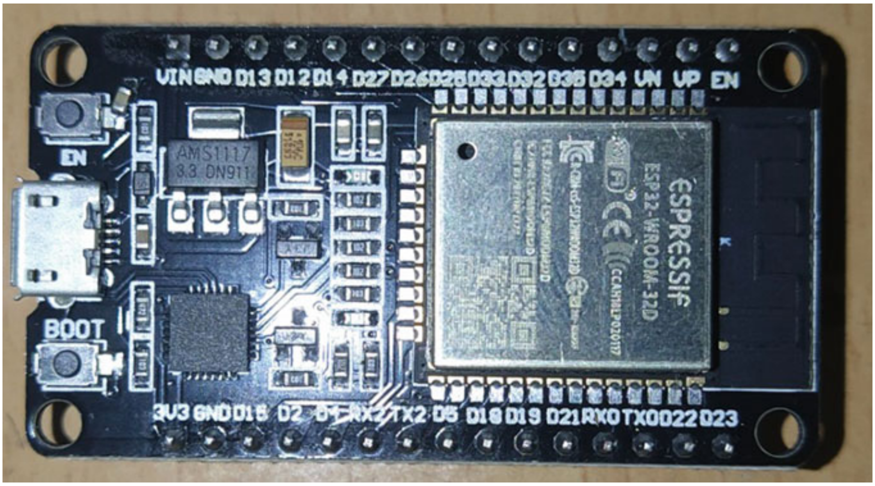

Fig. 7 ESP32-WROOM-32 microcontroller

3.2 Role of Web-Based Service Providers

There are many web-based freeware service providers in the world including IFTTT, Zapier, Huginn, etc., which play a key role in the development of this warning system. One of their function is to send short messages to provided mobile numbers when the moisture sensors read the threshold value of our soil, before failure. ESP32 microcontrollers can find the nearby internet provider and connect to the online service providers and give us the required message through mobile network. Hence, if the mobile number of every resident of the landslide-prone area is collected and made the recipient of such short messages, we can focus their attention towards evacuation and prevent major life-threatening situations. Figure 8 shows the working flowchart of the system developed.

Here, in this study, the ESP32 has been programmed to connect these web-based service providers to send short messages to the public when the point of threshold is reached. The system shows a response time of 4 s for an internet connection speed of

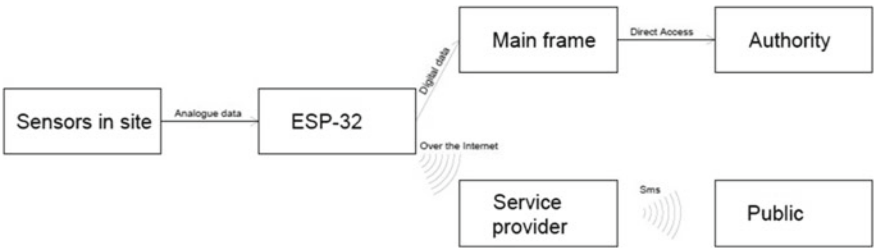

Fig. 8 Working flowchart of the system

10 mbps. The messages are delivered within 4 s from the point where the sensors read a moisture content of 13.5% moisture content. By considering the rainfall intensity, it seems to be a fair time for the evacuation process to start. The installation of sensors can be done by encasing the sensors to avoid outside interferences before embedding in into the ground.

This is one of the cheapest methods for an early warning system for landslides and can be used in any area, where there is a public internet facility is available.

4 Conclusions

To summarize, there are large-scale applications for multidisciplinary studies in civil engineering, rather than the conventional methods which can get us not that far. The methods given in this paper are very easy to learn for any civil engineer. The major conclusions that arise from this study are given below:

1. SEN0114 sensors can be effectively used to study the change in moisture content during rainfall.
2. The model study using locally available red lateritic soil, the slope failure occurred at 27% water content, when the rainfall intensity was 48 mm/hr and the slope is 60°.
3. There is a time gap between the occurrence of failure and the time at which the failure moisture content value was first observed.
4. Using ESP32 microcontrollers, a prototype web-based early warning system has been proposed.

This moisture content and the early warning system are applicable only for this soil at the given slope and rainfall parameters. It implies, where ever such a system is to be installed, a detailed model study using a rainfall simulator is very necessary.

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