Applications of Arduino sensors for detection of seepage failures in soil

Varun Menon O, Narasimha D S

Abstract— This paper deals with the development of an Arduino based detection technique for seepage failures like soil piping through embankments and landslides. The recent events, particularly the heavy rainfall caused flood have caused many catastrophic failures to the structures including buildings and roads, resulting in heavy casualties in many cases. The main reason being landslides, henceforth this study focuses on developing a prototype sensor pillar for such localities where the influence of moisture causes significant failure to the ground. The objective is to develop a low cost early warning system for better evacuation process. The study is bi fold, a parametric study and prototype sensor pillar development.

Index Terms— Arduino, detection technique, Soil piping, embankments, landslides, heavy rainfall and sensor pillar

1 INTRODUCTION

Seepage failure is just a general term for the failures that occur in civil engineering structures like dams, bridges, buildings etc due to intrusion of water in to the soil. The soil should resist the load coming on it from the above structure. The water presence determines the strength of soil, as the water content becomes more than plastic limit the soil tend to lose its shear strength [1].

This work focuses on the internal soil erosion detection on earthen dams and landslides. Soil internal erosion or soil piping is caused by internal seepage failure due to the movement of soil or rock in the form of a hollow cylindrical tube inside the earth due to the force exerted by seeping water. According to International Committee of Large Dams (ICOLD) the piping is classified in to five types. They are classical piping, progressive erosion, uplift or heave, scour, and suffusion [2]. From the statistics given by ICOLD, more than half of the earth embankment failure occur in the pre-1974 era is due to Progressive erosion and Suffusion alone.

Landslide is a natural disaster that causes because of many factors, main triggers for the landslide includes, Earthquake, Heavy rainfall, and artificial cuts in the soil. In tropical states the main cause that triggers landslide is heavy rainfall. The main causes behind both soil piping and landslide is excessive moisture inside the earth that causes soil to become loose and tends to displace from the initial position.

Currently there is no way to predict this phenomenon. The early detection of this phenomenon can divert a catastrophic failure. The objective of this study is bi fold. In the first fold, a parametric study of soil internal erosion occurring in the selected soil, here it is red earth and mainly conducting a modified Hole erosion test with various water heads. Main objective in this part would be to find out the coefficient of soil internal erosion (k_{er}) [3], which is defined as the time taken for water to completely penetrate through a unit length of soil sample. After finding k_{er} the parameters that affect this value is discussed.

Second fold of this study would be to develop a non-destructive method to detect the seeping water through the embankment by making an Arduino based low cost sensors that can be used to detect water presence. It will be Tested on a model that has been made with a monolithic material either by clay or concrete to validate the system will also be done in this part.

The objective also includes to check the plausibility of this sensor pillar to work as an early warning system for seepage

- *Varun Menon O is currently pursuing masters degree program in Geotechnical engineering in Cochin university of science and technology, PH-7736787173. E-mail: varunmenon.o@live.com*
- *Narasimha D S is currently the associate professor in the division of civil engineering in Cochin university of science and technology, PH-8547775943. E-mail: narasimhadhongdi@gmail.com*

failure, particularly Landslides, because landslide is also caused by soil internal erosion. The presence of excessive moisture causing reduction of shear strength to the top soil is the major cause of landslide [4] in the areas of heavy rainfall. This work also gives a positive output to the society for the betterment of safety against such disasters in the future.

2 METHODOLOGY

After gathering information from a good deal of literature carried out, the following are proposed. In the parametric study part of this project, the hole erosion test apparatus is made, mainly with PVC and other accessories required. In the standard hole erosion test [5], there will be a turbidimeter and digital displays, which makes it very costly and not necessary for the test setup required. Basically, this work requires an instrument that can measure the k_{er}, hence eliminated the unnecessary parts that are not required for the scope of work. Then made a simple apparatus as shown in Fig. 1.

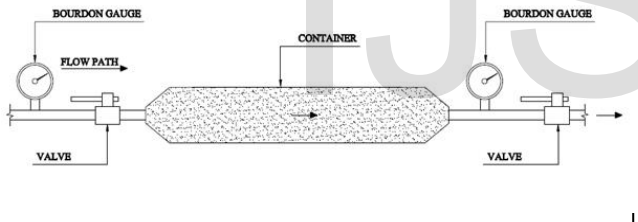

Fig. 1. Schematics of the test apparatus

It contains a sample tube of 350 mm overall length with two ball valves at the ends. The pressure gauges (100 psi range) are used to measure the head of water. First of all, the pressure gauges are tested with standard heads of water to calibrate it with the standards before initiation of the work. The test initiates as the pipe is connected with the water source and the valves will be closed. Then the water pressure is measured and recorded. Then the inlet valve is opened. The water will pass through the sample and will reach the outlet side. The time is measured from the instance inlet valve is opened till the pressure gauge at the outlet shows the same value as the inlet pressure gauge. Then the outlet valve is opened and allows the water to pass through. The time taken is used to find the ker value. The head loss due to the sampling tube is neglected as the sample tube is only 350 mm long. Then the test is repeated for different head of water.

In the development of detection technique for soil internal erosion part, study on the causing effects for soil internal erosion is discussed at first, and then a suitable detection technique is suggested. It requires the fundamental knowledge in electronic micro controllers and sensors. The Arduino development platform is used here, it is an open source electronic platform developed in Interaction design institute Ivrea, Italy. It is a very cheap and reliable micro controllers. The micro controller chip used inside an Arduino UNO R3 developer board, which is used in the present study is called ATmega 328P.

The Arduino has many applications, one of them is programming of low-cost sensors. In the Fig. 2 shows both the developer board and the sensors. The sensor in Fig. 2b is called soil moisture sensors. The working principle of this moisture sensor is as follows, the sensor gives a particular analogue reading to the micro controllers as and when the sensor is completely dry. As the dampness increases the sensor become more resistance to transmit these analogue readings and shows a decrease of analogue readings. The sensor is calibrated to identify the dampness percentage in the soil based on this principal. The components used are given in Table 1.

A sensor pillar embedded into the soil will be a viable solution for detecting the problem. The sensors will be programmed such that, it will give the warning to the respective authority to stop and evacuate that area whenever a particular soil moisture level occurs and this level of critical

Fig. 2. a) Arduino UNO developer board b) Soil moisture sensor

moisture content depends on the slope stability of the area and type of soil,

which has to be predetermined before installing the sensors in the ground.

To understand parameters affecting soil internal erosion, a modified hole erosion test setup was made. Partly cohesive soils like laterite have a higher probability of soil piping. But it also happens with clay as well [6].

TABLE 1

REQUIREMENTS FOR DETECTION TECHNIQUE

Item	Number of items	Remarks
Development board	2	Arduino UNO R3
Circuit boards & Wires		As per requirement
RF transmitter	1	433 MHz Arduino compatible module
RF receiver	1	Compatible with the transmitter
Moisture sensors		As per requirement Maximum 6 per Development board
Computing system	1	Installed with Arduino IDE

The parametric study was previously done by Benahmed and Bonelli [3] on Hole erosion test apparatus. A series of hole erosion tests were carried out under constant flow rate in order to quantify the critical shear stress and the coefficient of piping erosion (k_{er}) of soils. Parametric study includes the experiment with different types of soil and verify how the particle size and the fl ow rate influences the coefficient of piping erosion. A cylindrical cell with compacted soil sample is provided at the middle. This apparatus contains two pressure gauges at inlet and outlet to measure the infl ow and out flow pressure and thus calculate the hydraulic gradient. A turbid meter is provided at the outlet for measuring the amount of mass transferred through the piping formation. A predetermined hole is made through the center for the initiation of the piping through that path only.

3 EXPERIMENTAL STUDY

The major steps involved in the experimental study includes the basic properties of the sample taken for the entire work is to be found, the index properties play a very good role in determining the piping potential of the soil. This study mainly focuses on the least resistant types of soil, as the piping probability in these kinds of soils will be higher. Such types of soil, if it is used in the construction of earthen dams, the detection techniques play a very important role for the safety of the society. It is common knowledge that, mostly while the construction of the earthen dams, the local soil is used for economic purpose. Here we are taking a clayey type soil in the first look.

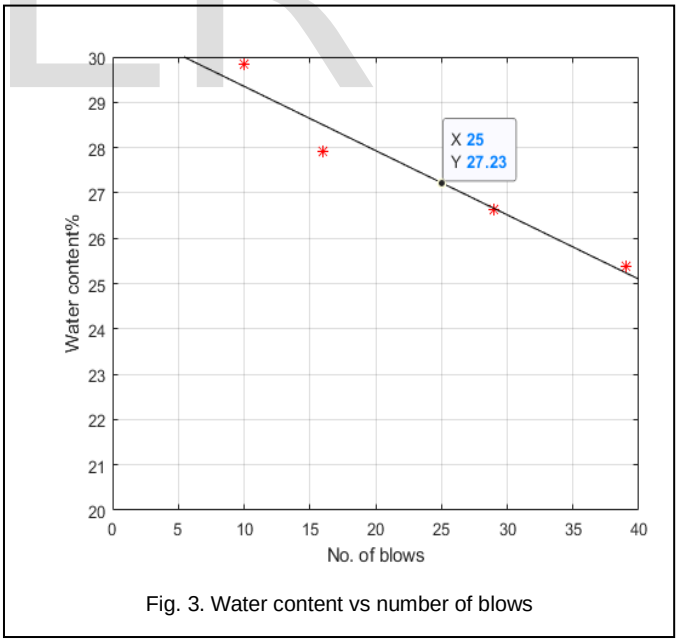

Fig. 3. Water content vs number of blows

Plastic limit was found to be 12.6 and Liquid limit is 27.2. Hence, Plasticity index is 14.6.

The results obtained from the modified hole erosion test is as Table 2.

From this study we can understand that the soil piping is inevitable in case of only soil in contact with water. This is

accelerated in real world scenarios like cracks due to earth-quake and dynamic loading. So as the water head increases the time required for the fully penetration of soil sample decreases. In case of addition of barriers can be helpful for the soil to withstand piping. That is why in most of the earthen dams, the core is made with impermeable fine clay and reinforced with geosynthetics.

TABLE 2

MHET OBSERVATIONS

Water pressure (Psi)	Time (sec)	Ker (Sec/m)
5	213	608.57
10	130	371.43
15	115	328.57
20	107	305.71
25	92	262.86
30	75	214.29
32	70	200

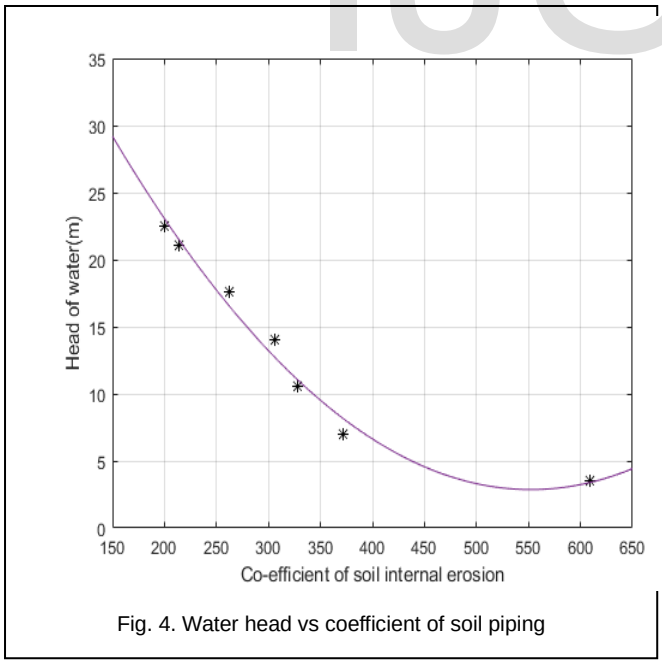

Fig. 4. Water head vs coefficient of soil piping

4 DEVELOPMENT OF DETECTION TECHNIQUE

The principle behind the working of this sensor pillar is as given in fig 5. Basically, there will be two modules, one for transmitting the analogue signal through a micro controller and other for receiving this data and will be far away from the location of installation of the sensors. Fig 6 shows a scaled modal of engineered earth dam with downstream slope of 1:1.8 and upstream slope of 1:2.

After the completion of the work the Model has been set still for 24 hours with a little bit of water on the upstream side to ensure there is no leakage. To predetermine the piping path a narrow stick is inserted through the core. After 24 hours, the tank is completely fi lled with water and the readings of the sensor is recorded with a small android based computing device. The data collected is shown in fig 7.

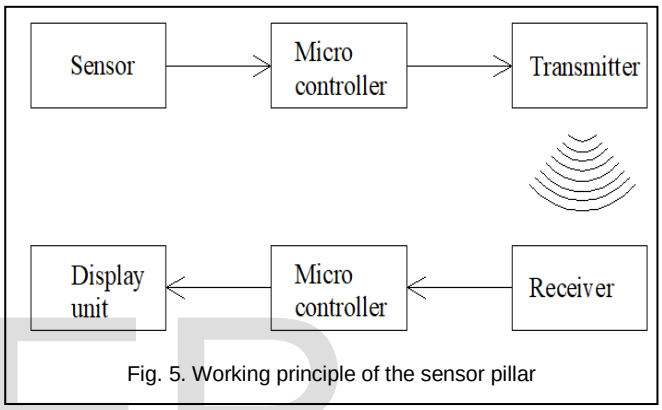

Fig. 5. Working principle of the sensor pillar

The warning signal was set of at some time after the removal of the stick for the piping to occur and exactly after 18 minutes and 20 seconds the breach of water was observed on the downstream side at around 10 cm from to bottom. Phreatic line is visible as the soil have been saturated. The test was started at 2:34:39 PM and the initial reading was shown as 5%, this could be due to the natural moisture content in the soil.

The sensor has started showing variations from 2:51:47 PM. And at 2:53:13 PM, the warning signal has been shown by the light emitting diode installed with the setup. And at 3:11:33 PM a breach has been formed at the downstream side. From the data obtained from the experiment, we can see that the major variation occurs at 46th to 83rd seconds. That means with in 37 seconds the readings have been recorded and at this time we can assume that the piping has breached the core of the dam and with in 18 minutes and 20 seconds a complete breach is occurred in the downstream.

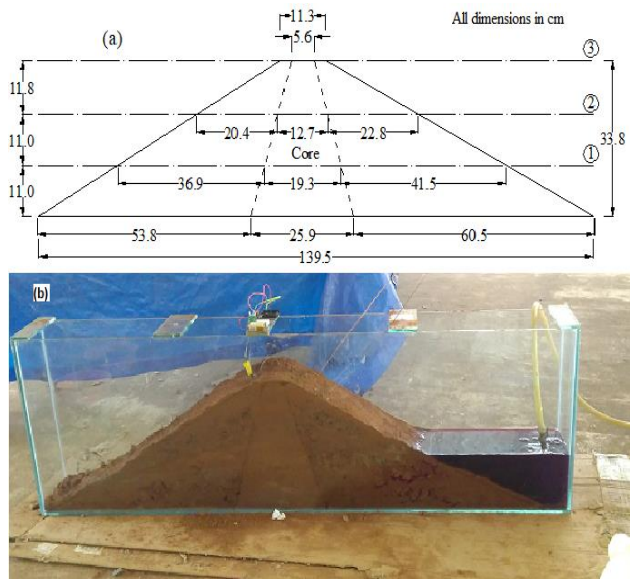

Fig. 6. (a)Schematics of the scaled model and (b) Erected earthen dam model

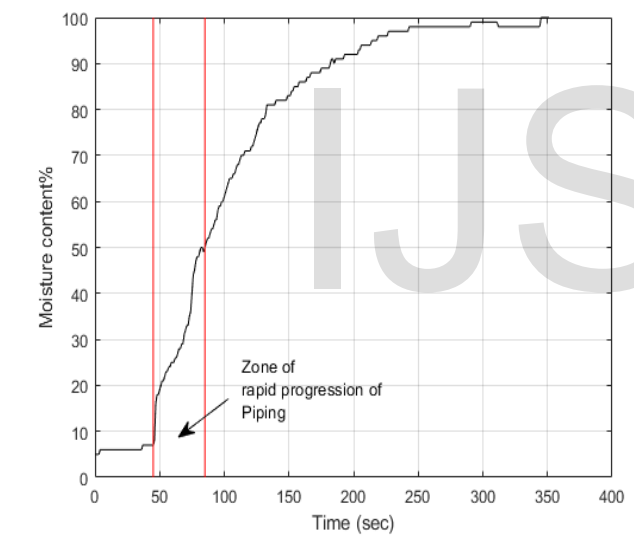

Fig. 7. Moisture content vs Time graph obtained from sensor

With further calibration and regression analysis, we can improve the warning system for giving edible time for evacuation and maintenance of the earthen dam. From the data occurred from the sensors, it can see that the piping is a very rapid process once it gets initiated. And the effect on the downstream is an inevitable breach. The installing of such moisture sensors in various locations of the earth embankment can increase the caution and give edible warning for maintenance and evacuation.

5 SUMMARY AND CONCLUSONS

From this study, the results obtained was very helpful to understand about soil internal erosion even though this study focus on the internal erosion in a guided path and also the mechanism of through the embankment is only considered. The Prototype is fabricated. Arduino IDE and MATLAB was used for the most part of this work and concluded that the sensors have a very great future in the field of civil engineering. This technique can also be implemented as an early detection and warning system for landslides and other seepage failures.

HET apparatus has been modified and done the parametric study of the selected sample. The resulted are tabulated and found the relation between head of water and the time of contact of water. The parameters that mainly causes soil internal erosion are Water pressure and Time of contact of water. The seepage of water is a very interesting phenomenon and a study of such in red earth, which is a low plasticity clayey soil is conducted and the results are obtained in the present study. Successfully assembled and tested a piping detection technique for earth dams which is extremely cheaper than the existing techniques. The sensor pillar is successfully tested in the prototype and can be used for actual structure in the coming future. As there are no permanent solution for soil piping and other seepage failure, an early warning system is suggested for a safer society. The detection technique also has other applications where the presence of water is required to be known. Landslide is also a seepage failure in the heavy rainfall zones. A landslide warning system is also plausible with the technology in the present study.

ACKNOWLEDGEMENTS

Our sincere gratitude towards Dr. Gangadharan K and Dr. Prithviraj U of Center for system design, NIT Surathkal. Also, the facilities available at Cochin university of science and technology were exploited for the purpose of completing this study.

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