Review of experimental studies on rainfall-induced landslide using the laboratory flume technique

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Abstract. Rainfall Induced landslides are one of the most influential disasters in the monsoon season for rainfall-rich parts of India, primarily southern and northeastern. Landslides are geotechnical phenomena that can be studied by conducting field experiments, laboratory experiments, and numerical modeling. Various methods can be adopted to study landslides, and the Landslide flume seems to be one of the most widely used techniques for laboratory simulation of the landslides. The scaled models created in a flume can represent the real-world situations so far, which will be reviewed here. The essential aspects of this review include the practicality of the flume experiments from the previous findings, how they can be related to the real-world scenarios, the difference between field instrumentations and laboratory instrumentations, discrepancies that can occur due to the scaled effect of laboratory simulation, and recommended techniques for the future development of laboratory simulated landslides with tilting type flume incorporated with a rainfall simulator.

Keywords: Landslide, Flume, Rainfall, Instrumentation.

1 Introduction

1.1 General

Human interventions such as deforestation, incorrect construction operations, and natural factors such as heavy rainfall and earthquakes are the leading causes of landslides. Due to excessive rain in 2018 and 2019, the states of Kerala and Karnataka experienced massive losses in multiple small and large landslides, mostly in rural regions. It needs a low-cost method to stabilize the slopes and reinforce the soil. Highway Authorities are always on alert to find out the most efficient way to protect the infrastructure to avoid any sudden collapse of soil mass, which will cause a time-consuming process of cleaning up the mess and life-threatening to the passengers. The recent trend in the drastic increase in rainfall has shown that climate change has adversely affected the infrastructural development and sustainability due to disasters like floods, landslides, soil erosion, etc. The rainfall event frequency and shallow landslides seem to be increasing, showing clear indications of climatic changes and human intervention [1–3].

It indicates that the rainfall is directly related to the landslides in the high precipitation zones. Thus, the need for a Landslide Early Warning System (LEWS) to predict rainfall-induced landslides is crucial. Hence there should be in-depth knowledge about Landslide mechanics. The most effective method to study rainfall-induced landslides is a landslide flume study incorporated with a rainfall simulator [4–9].

1.2 History

Landslide flume study can represent the real-world conditions that arise from the complex mechanics of landslides to a more scaled model. Henceforth the study can be much simpler, and geotechnical parameters can be controlled. The Important tool for any experimental work is the amount of data and measurements that can be taken. Instrumentation also plays a very significant role in any Laboratory experimentations. As the technology improves, the tools that can be used will become more sophisticated.

Eckersley [10] has done pioneer research using a flume to analyze the effects of the water table in the coal stoke piles. A large glass tank is used, where 1 m high stockpiles can be constructed. The flume's size will depend on the scale of the model used. Cameras and Instrumentation techniques, such as hydraulic piezometers, pore pressure transducers, temperature probes, and total stress cells, were used. A data logger is used to record the data. There has been a rapid generation of pore water pressure in the model, which caused the model profile to be very flat. It is concluded that the failure in the flume experiment is similar to the failure in the field. In almost all the cases, the Camera and pore water pressure transducers seem to be one of the most valuable instruments for geotechnical laboratory flume tests [11].

In a few kinds of research, the flume is fixed with a counterweight to allow the flume to tilt, and the effect of a landslide can be demonstrated. Spray nozzles for simulating rainfall are also used [8]. The study focuses on liquefaction flow slides, and according to Kramer, fine silty sands are more susceptible[12]. Most pioneering and relevant workin landslide mechanics came with Okura et al. [4]. Several theories conclude that pore pressure generation occurs when the soil layers tend to contract during events like rainfall and seismic activities. The basic instrumentation includes pore pressure sensors and cameras for measuring landslide motion. Most tests are in sandy soils with a considerably smaller slope value. The tilted flume used by Okura et al. is as long as 9 m long and 1 m wide.

Acharya et al. used sandy soils in different soil depths and found the sediment deposit during shallow landslide events [9]. A flume technique has been adopted for conducting the tests where rainfall simulators with Veejet Nozzles [13] have been used.Here also, the use of Pore pressure transducers and cameras can be seen, and the moisture sensors are used additionally to identify the moisture content at failure. the results obtained are very helpful to identify the probable failure moisture content for sandy soils and also the slope profile related implications to any slope failure. One practical use of a flume experiment is controlling the environment and real-world simulation. Because of that, much work has been done to find an effective way to develop a landslide early warning system [7].

Cogan and Gratchev conducted flume experiments on a smaller scale model and developed an intensity duration threshold function, $I = 80.065D^{-0.596}$. Where I is the rainfall intensity (mm/hr) and D is the duration (hr) [14]. But the study seems to be lacking accuracy when it comes to a bigger scale and if the rainfall happens for a higher intensity for a shorter duration. Also, the tests, like all other cases, have been performed on the sand.

2 Instrumentation

Good results in any experimentation are as good as the instrumentation for monitoring. A low-cost sensor will always be less accurate and robust than an expensive one. The question is whether you need such efficiency or not. Before any experimental work, there should be in-depth market research on the sensors and technology available to get the best one for the price. Each instrumentation comes in different resolution, reliability, ruggedness, and durability. So it is crucial to identify the most suitable one with the requirements of the work [15]. It isn't easy to obtain reliable data only depending on conventional engineering practices [16]. The knowledge of inter-disciplinary subjects is also an added advantage to the future of the field. Using adequate sensors, the data obtained can be used to conduct a parametric study involved in the mechanism of landslides. The important parameters that are required to be monitored in a landslide flume study would be, Rainfall intensity, Excess pore water pressure, and Structural Integrity of the slope. The instruments that can give such data include Pore pressure sensors, Flow meters, and Accelerometer sensors. Even Moisture and Temperature sensors can be adopted to check the infiltrating water in the soil mass. Cameras with technology similar to Light Detection And Ranging can also be used to check the surface variations and profile the slope failure.

Landslide is a phenomenon that cannot be stopped and predicted by the existing technology. Slope monitoring seems to be a viable solution for landslide hazard assessment [17]. In most cases, it is observed that the precipitation triggers landslides [18]. The study on low-cost landslide monitoring systems has been done previously by several researchers, and some of them are made with micro-controllers like Arduino [19], but these machines lack the durability and robustness needed to work in a real-world scenario; hence pilot studies on relevant sites are recommended with using better systems to improve the quality and precision of such sensors before deploying it commercially.

Wand and Sassa have incorporated laser displacement techniques to measure the surface deformation in the experiments [20]. And noticed high pore pressure built up before any significant surface deformations. Some studies also show the use of Tensiometers to measure the effect of suction. As the moisture content increases, the suction decreases, and the safety factor against failure will decrease. Most researchers are only using sand to study the behavior of the slope failure, whereas most of the soil in the affected area also has silt and clay content. The study is beneficial to find out the critical intensity-duration of rain during failure events. And it is found that the failure surfaces from the test are mostly translational [21].

MEMS (Micro Electro Mechanical System) accelerometers are used to detect the ground motion by Ooi et al.[22]. after a comprehensive study of the previously done works, a soil box that can change the slope angle has been made. The work promotes cheap open-source sensors repurposed to monitor a landslide event.

3 Future Scope

One of the significant future scopes of the flume technique will be to use it for developing a LEWS that will have an enormous implication on the country's socio-economic growth. A landslide warning system is an advanced geotechnical instrumentation technique that can detect the early signs of an impending disaster and help society and government officials take necessary precautions. The concept of geotechnical instrumentation is not new. From the inception of geotechnical engineering, field monitoring has started, and many works of literature support that as well [15, 23–27]. The world has become technically sound that we can measure the dimensions of any object using a camera or mobile phone and predict the weather from the weather applications and websites available. So the technology is there, we suggest, merely repurpose and train that technology such that we can use them to identify the soil characteristics and the effect of rainfall in the soil that may cause a landslide well before it is initiated to save human life. Suppose the LEWS is located at a particular location and the weather has reached such an adverse condition that the landslide is imminent, with the help of the real-time data collected and the warnings obtained from the proposed LEWS. In that case, the authorities can restrict the entry to the landslide-prone location and advice the citizens to evacuate as soon as possible from this region. A simple working principle is shown in Fig.1, an illustration in Fig.2, and the proposed flume setup for conducting the laboratory experiments is given in Fig.3.

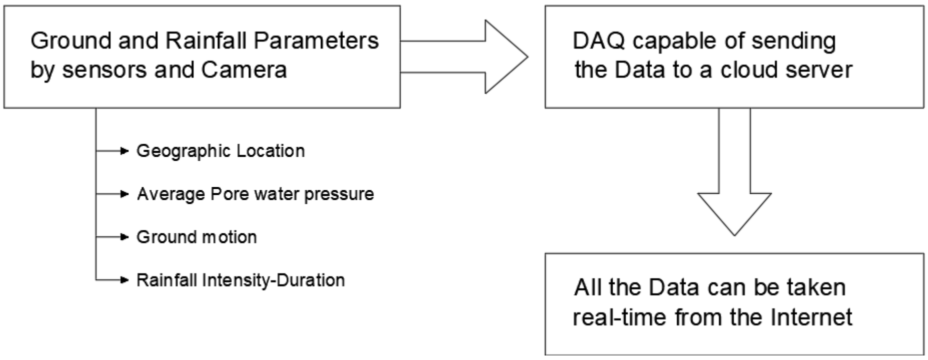

Fig. 1: Proposed Working Principle of a LEWS

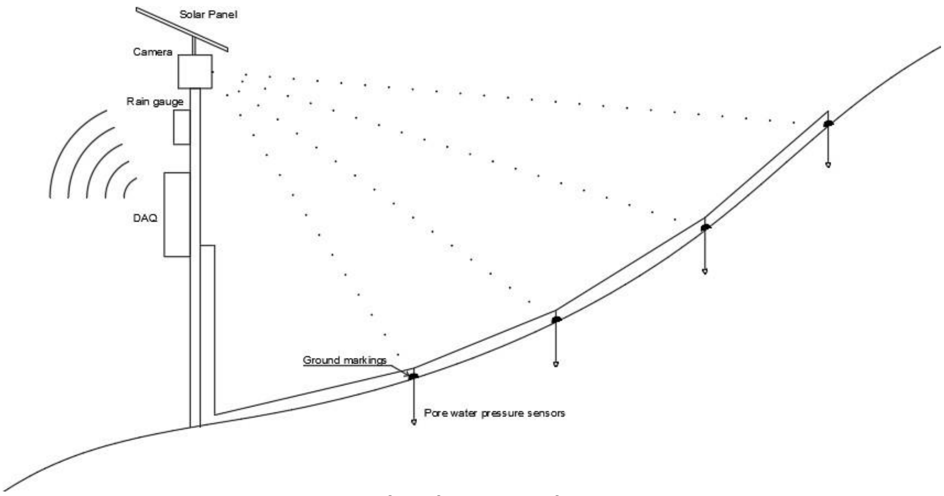

Fig. 2: Illustration of the field setup of LEWS

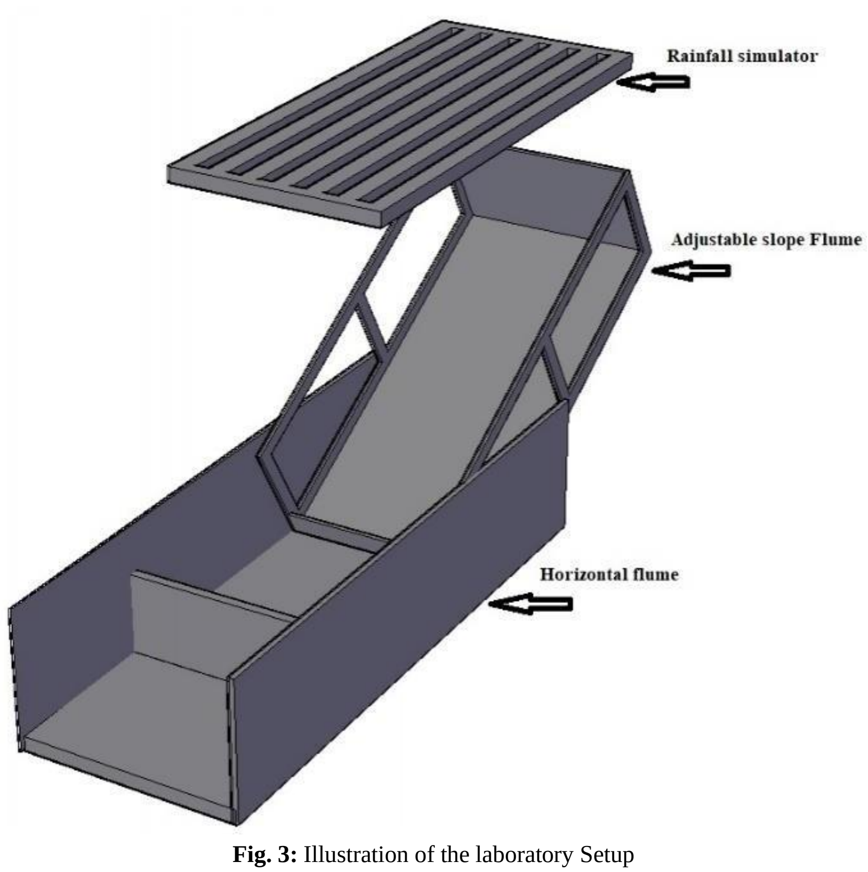

Fig. 3: Illustration of the laboratory Setup

4 Conclusion

- The Flume technique can be used for multiple purposes. Here we have reviewed some famous studies on Landslide mechanics of the rainfall-induced landslides.
- Various instrumentation techniques used have been covered in this paper.
- The studies on the intensity duration of critical rainfall threshold and development and calibration of a LEWS can be done with the proposed tilting type flume as given in Fig.3.

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