Experimental Investigations on rainfall induced landslides

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Abstract. In recent times, occurrence of natural hazards in India and around the world is increasing day by day. Landslides are one of the most destructive natural phenomena which not only causes extensive damages to the structures but also results in loss of lives. Among various factors, rainfall is one of the most important triggering factors for inducing landslides. In most of the time during rainfall, due to infiltration of water in to the soil, the pore water pressure increases which destabilizes the slope resulting in landslide. This paper presents detailed laboratory experimental studies on the behaviour of rainfall induced landslides. For experimental testing, indigenous test system has been developed at CSIR- CBRI for investigating rainfall induced landslide. The system comprises of a tilt channel and artificial rainfall simulator system. The arrangement of rainfall simulator can able to reproduce landslide triggering under varying intensities of rainfall with uniform rain distribution. For the present study, a model slope was created with the landslide debris soil material brought from the Lesser Himalayan region of Uttarakhand State. After soil characterization, rainfall experiments were conducted on the equivalent slope model using artificial rainfall simulator system. The rainfall experiments were performed with rainfall intensity equivalent to some reported high rainfall intensity experienced in the past in the Himalayan region. During rainfall experiments, the increase in soil moisture and soil movement was monitored continuously. The time at which slope failure initiated was observed and corresponding soil moisture and slope movement pattern was evaluated. Finally the mechanism of slope failure was analysed and possible slope protection measures were suggested

Keywords: rainfall induced landslide, artificial rainfall simulator, and slope stability

1 Introduction

Rainfall induced landslides pose major problems in steep hilly terrain regions. The reduction in soil strength due to water infiltration destabilizes the slope and creates huge problem to population in the region every year. Although there are number of reasons responsible for creating instability in slopes, many failures occurs mainly due to rainfall infiltrating stable slope. The ingress of rain water infiltrates in to the voids creating cracks which propagates further creating failure with continuous rainfall. To validate and examine slope stability, there are softwares available through which the existing slope model has been generated and analysed for estimating factor of safety of the slope. To examine rainfall induced slope stability analyses, change in ground water level has to be incorporated in the numerical analyses and factor of safety of the slope was estimated. When the given ground water configuration simulating actual conditions for the existing slope, the analyses provides accurate prediction. However in most of the cases, the actual ground water conditions were not considered which results improper estimation of factor of safety of the slope. Thus only experimental study provides possible triggering mechanism associated in rainfall induced landslides.

To simulate rainfall induced landslide mechanism experimentally, various researchers worked in different landslide conditions and concluded that rainfall induced landslides occurs due to different mechanism. Johnson and Sitar (1990) and Fannin and Jakkola (1999) studied pore water pressure generation in slope under saturated conditions with intense rainfall conditions and modeled ground water seepage affecting the stability of the slope. Also several researchers during their experimental study observed slope failure due to rainfall infiltration and without formation of pore water pressure in soil and found slope failure mainly due to loss in unsaturated shear strength (de Campos and Menezes 1991; Rahardjo and Fredlund 1995). From these studies researchers found that rainfall induced landslides is a complex problem involving analysis seepage forces, soil infiltration characteristics under saturated and unsaturated conditions and shear strength of soil under saturated and unsaturated conditions. Additionally, the researchers found that for simulating rainfall induced landslides better, the experimental facility requires effective artificial rainfall simulator system. Also the rainfall simulator system should simulate rainfall conditions equal to natural rainfall in terms of drop size, intensity, uniformity and should not erodes the soil mass from slope.

The present study involves in developing an artificial rainfall simulator system can able to generate varying intensity of rainfall from 30 mm/hr. to 130 mm/hr. Then using artificial simulator facility, model slope was prepared with the debris materials collected from Lesser Himalayan region and the slope was tested for rainfall induced landslide testing conditions. Using soil-moisture sensors, the rise in volumetric water content was monitored continuously and the time of initiation and occurrence of slope failure was identified. Finally possible slope protection measures for improving stability of slope under rainfall conditions was discussed and presented.

2. Development of rainfall simulator system

For development of rainfall simulator system, a pressurized multi nozzle arrangement has been designed. The nozzle system was designed such that improving infiltration characteristics rather than creating soil erosion. Accordingly, the pattern and location of nozzles has been selected. For the present study, it was planned to develop rainfall intensity of 30 mm/hr. to 130 mm/hr. To achieve this selected intensity, nozzles were placed in square pattern having centre to centre distance of 0.5 m at 1.4 m height above the laboratory test fume. The nozzles were positioned above test fume and calibrated for the selected intensity of rainfall. Using pressure regulator, the water flow in to the nozzles was controlled and accordingly intensity of rainfall was maintained. To improve maximum uniformity in rainfall distribution the arrangement of nozzle system was made in three rows with 10 nozzles in each row. Schematic view of entire set-up was shown in Fig.1.

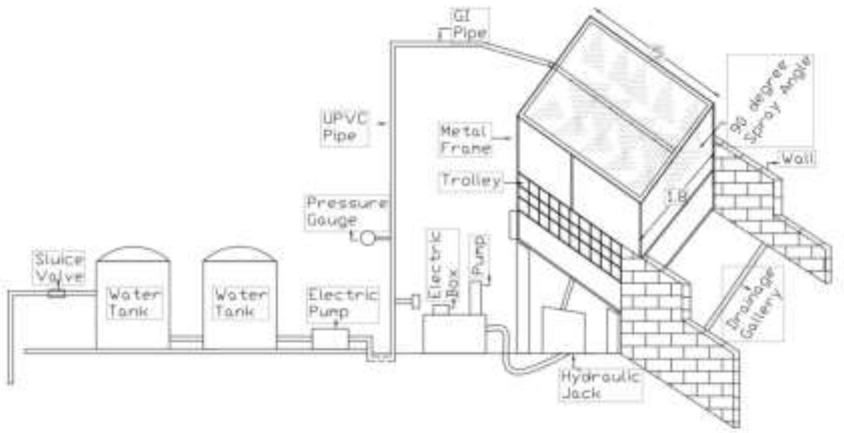

Fig.1. Artificial rainfall simulator system

3. Experimental Studies on rainfall induced landslide testing conditions

Heavy rainfall in slopes increases pore water pressure inside the soil causing reduction in strength and makes the slope unstable. To evaluate the effect of rainfall in slope stability, slope was prepared and tested under artificially simulated rainfall conditions. Tests were conducted on large scale model fume having dimensions 5m×1.5m×1.0 m. To reduce side wall friction effects, the side walls of the tank were made with thick perspex material. For experimental study, debris material collected from Lesser Himalayan region was selected and soil characterization was performed. The properties for the collected debris material were given in Table.1. After soil characterization, soil slope was prepared. For testing, slope having 2 m× 1.5 m× 1m dimensions was constructed. The crest and toe length was kept as 0.5 m and 0.4 m respectively with slope angle 37°. To minimize scaling effects mass density and geometric size were taken as control variables. The slope was prepared with 19.2 kN/m^3 mass density and with corresponding 13% water content. For slope preparation, the required quantity of soil was calculated and slope was prepared in three layers to achieve maximum uniformity. The slope was then subjected to a rainfall intensity of 100 mm/hr. To measure variation in volumetric water content during rainfall, three soil-moisture sensors were installed at crest, slope face and toe position of the slope. The slope was then subjected to a continuous rainfall for 150 minutes. The slope was monitored continuously to observe variation in volumetric water content during rainfall. The slope and rainfall system also verified to ensure that, the generation of rain drop should be sufficient to infiltrate in to the prepared soil mass and does not initiate any soil erosion characteristics.

Table-1 Properties of the Debris soil

1.	Specific Gravity, G	2.7
2.	Grain size analysis	Gravel - 4% Sand - 48% Silt -35% Clay -13%
3.	IS classification	SM
4.	MDD	19.2 kN/m^3
5.	OMC	15%
6.	Cohesion, C	9 kPa
7.	Angle of internal friction, φ	36°

4. Results and Discussions

The observed variation in volumetric water content (VWC) with time was given in Fig.2. When the slope was subjected to continuous rainfall, slowly the slope gets saturated with the increase in time. The same can be verified from incremental part of volumetric water content in the graph. As expected the increase in volumetric water content was found to be maximum at crest and toe. Comparatively lesser variation was observed in slope since limited infiltration is possible slope position. After continuous rainfall, due to infiltration the slope get saturated completely which initiate rise in pore water pressure inside the slope. When there is an increment in pore water pressure, small displacement was observed from crest of the slope. The displacement propagates further which creates instability of the slope. The same was observed after 90 minutes. After 90 minutes, cracks get wider at crest of the slope, travels further to slope region causing shallow type failure. After 140 minutes, the slope experience shallow type slope failure. The failure pattern of the slope mass was shown in Fig.3. The ingress of water inside the slope suggesting that, infiltration plays a major role in affecting stability of the slope. Due to infiltration the water penetrated in to the slope causing water table fluctuation and increases pore water pressure. When pore water pressure increases, the shear strength of the slope reduced causing slope failures. This was evident from the experimental study. Hence to mitigate rainfall induced landslide, the slope was protected from rainfall infiltration i.e. providing geosynthetic reinforcement system. The selected geosynthetic materials should have alternate permeable and impermeable layer such that it prevent water infiltration during rainfall and also relieves generated pore water pressure inside the slope due to variation in ground water table conditions.

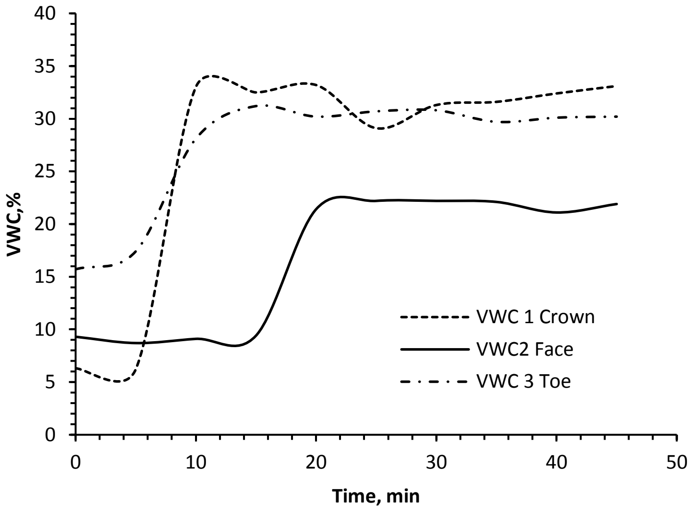

Fig.2. Variation in volumetric water content with time

Fig.3. Slope at failure

5. Conclusions

Rainfall induced landslides always pose problems in hilly regions. Hence before implementing stabilization measures, it is important to understand the geologic origin and geotechnical characteristics of the slope. Also, the mechanism of rainfall induced landslides varying for different regions. Considering the above an attempt has been made to study the characteristics of rainfall induced landslides using debris material from Lesser Himalayan region. To simulate rainfall conditions, artificial rainfall simulator has been designed and slope was tested under rainfall conditions. It was observed that, infiltration plays a major role affecting shear strength of the soil resulted in destabilizing the slope. Due to water infiltration, the slope gets saturated with continuous rainfall and after saturation, the pore water pressure increases causing instability to the soil due to reduction in soil shear strength. To mitigate this rainfall induced landslide, the slope should be protected from infiltration especially in crest part. To minimize these infiltrations, providing geosynthetic confinement over the slope covering crest was suggested. Also the geosynthetic system should consists of both permeable and impermeable membranes such that it protects the slope from infiltration and also minimizes the generation of pore water pressure thus improving the stability of the slope.

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