ABSTRACT

The cases of sliding failure of slopes, road and railway embankments and industrial dump fills are abundant in the world. Depending upon the location of the failed slope, it may cause a serious disaster in terms of loss of lives and properties. A naturally occurring soil slope is seldom homogeneous. It may consist of different types of soil. Some of the layers may be weaker or stronger than the overall soil mass. The study of the stability and the stability mechanisms for a non-homogeneous, unsaturated soil slope due to the presence of a stronger but less permeable soil layer has not drawn enough attention. The common belief among engineers is that the presence of a stronger soil layer within an otherwise homogeneous soil slope is of no concern as the stronger soil layer shall not fail or fail later. But if the relatively stronger soil layer has less permeability, it may cause hindrance to the natural flow of the infiltrated rainwater or ground water and this may result in pore water pressure build-up within a slope. The present study explores the effect of an embedded, less-permeable, stronger soil layer on the stability and the stability mechanisms of unsaturated, non-homogeneous soil slope with and without rainfall condition by laboratory model tests and numerical analyses.

The present study includes two different types of experimental model tests - centrifuge model tests and laboratory 1-*g* model tests. The 1-*g* model tests have been performed under varying rainfall conditions on homogeneous sand slopes and non-homogeneous sand slopes with embedded less-permeable, stronger, silty sand layer(s) at different heights of the slopes. Tests are performed on 45˚ and 35˚ inclined slopes of unsaturated soils with an initial moisture content of 10%. A limited number of centrifuge model tests have been also performed on the homogeneous and the non-homogeneous, unsaturated slopes with less-permeable, stronger soil layers at different heights of the slopes. In the case of centrifuge model tests, as no slope failure occurs in the 45˚ slope inclination, a higher slope inclination of 55˚ is chosen. All the model tests are analyzed numerically using a computer program, called GeoStudio. The developed numerical model is also applied to investigate a rainfall-induced landslide at Malin in Maharashtra, India.

It is observed that the 45º and 35º homogeneous slopes do not fail under 60mm/hr and 90mm/hr of rainfall in the model tests. Only fluidized shear zone is observed at the toe of the slopes during higher intensity of rainfall, like 90mm/hr. However, 45º and 35º non-homogeneous soil slopes with the inclusion of a stronger layer with lower permeability

trigger a slope failure. The 60mm/hr and the 90mm/hr of rainfall produce a perched water table just above the less permeable silty sand layer, which moves in the upward direction with the rainfall duration. The increasing size of the perched water table reduces the effective stresses and the shear strengths of the soil which leads to a shear failure just above the less permeable stronger silty sand layer. In the case of 30mm/hr of rainfall, no such perched water table is developed in 45˚ and 35˚ slopes and the slopes are found to be safe against sliding. It is also observed that, in the cases of 45˚ slope, the shear failure plane is much wider and deeper as compared to that in the 35˚ slopes. The presence of a less permeable, stronger (NH) layer near the crown makes the slope more vulnerable within a shorter duration of rainfall. As the infiltrated rainwater, coming from the top, accumulates on the less permeable layer and positive pore water pressures develop in the soil within a shorter period, a slip failure is initiated with the failure plane passing just above the NH layer.

In the centrifuge tests on 55˚ slopes, it has been observed that the homogeneous slopes do not fail and no significant shear band is observed. But, in the cases of non-homogeneous soil slopes with embedded less permeable, stronger, silty sand layer, prominent shear bands are observed for the same slope angle and same slope height. With the less permeable, stronger soil layer at $2/3^{rd}$ height and mid-height of the slope, two shear zones are found to develop. The one, just above the stronger layer, is fully developed. The second one, which is partially developed, initiates from a little above the toe and terminates at the stronger soil layer.

The present study indicates that not only the shear strengths but also the soil type, its characteristics and its permeability relative to other soil layers play a vital role in the overall stability of a slope.

The numerical investigation into the rainfall-induced landslide at Malin, India indicates that the continuous rainfall infiltration develops a perched water table near the slope surface at Malin. This results in the saturation of the slope materials and build-up of positive pore water pressures at shallow depth. With the increasing intensity and the duration of rainfall, the depth of this saturated zone within the slope increases rapidly making the slope vulnerable. It is observed that the slope, on which the Malin village is located, is safe but not entirely secured because of the failure of the upslope. The failed soil mass would move from the upper part in the downward direction and destroy the Malin village as observed in the reality.

Keywords: Non-homogeneous slope, rainwater infiltration, factor of safety, centrifuge model test, unsaturated soil mechanics.