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Numerical simulation of vegetated mine dump slope with reference to small plants

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ABSTRACT

The present paper discusses the effects of small plants on the dump mass reinforcement and slope stability. The roots of smaller plants (such as grasses and shrubs) do not go deep. However, they stabilize the slope by binding the upper layer of dump slope. Shear strength of the dump mass with and without root reinforcement is determined by laboratory shear box instrument. The increased cohesion (apparent cohesion) of upper layer of the dump mass due to plants is determined by fabricated shear box. The kinetic behavior of the dump has been investigated using the FLAC software. The factor of safety has been calculated in order to determine the possible effect of small plants on the stability of the dump slope. It is observed that the small plants do not significantly improve the factor of safety (FOS) of slope. However, it could be useful for early stabilization. The grasses quickly bind the upper surface, whereas shrubs too immensely strengthen the stability of the dump in the initial stage.

1. Introduction

Vegetation is widely used to control the soil erosion and stabilize slopes. It affects the stability of slope in two ways, i.e., mechanical and hydrological. In mechanical effect, the small roots of vegetation mobilizes their tensile strength by increasing soil–root friction of the compound matrix (soil–fiber), whereas, the large size roots intersect the shear plane; act as individual anchors and eventually tend to slip through the soil matrix without breaking, mobilizing a small portion of their tensile strength [1,2]. The role or effect of smaller plants in stability of slopes is more different than that of the large plants. The roots of smaller plants (such as grasses and shrubs) do not go very deep; however, it stabilizes the slope by binding the upper layer of slope. It also prevents the rain water from infiltrating into upper layer of slope [3]. The roots of the large plants (such as trees) go deeper into the slope and act as permanent stitching material. It increases the shear strength of rock mass in general and weakness joint planes in particular. However, tree takes longer time to grow and significant contribute in slope stability.

The affect of soil stabilization by plant roots are based on two components: (1) by friction between the soil particles that transfer shear stresses from the soil to the root reinforcement system, and (2) by soil arches that build up between cylindrical soil units that are reinforced by roots (root stock-soil elements) and stabilize areas that are not rooted. Usually, the only effect considered by most of the authors is the fiber reinforcement expressed as additional root cohesion which can be easily incorporated into spatially distributed slope stability models [4–9]. A theoretical model has been developed to calculate slope stability of infinite slope [10]. Shear boxes were used to associate tensile force exhibited by a root with the apparent increase of shear stress [11]. A direct shear box test can be used to determine the cohesion of vegetated soil. Shear strength of a soil or resistance to failure can be expressed as a modification Coulomb's law, Eq. (1).

$$\tau_S = c + c_r + (\sigma - \mu)\tan\phi \tag{1}$$

where τ_S is the soil shear strength; c the effective soil cohesion; c_r the apparent cohesion due to roots; σ the effective normal stress; μ the water pressure; and ϕ the internal friction angle of the soil. Roots of plants produce an apparent cohesion (root cohesion) in the material via root fiber reinforcement. The root cohesion varies with types of vegetation, age of plants and types of materials [12–15].

Stability of dump slope in surface mines is a major concern to mining engineers. Dump failure may lead to stoppage of the work temporarily, accidents involving men or machinery or both. The cost of dump failure may be high, depending on the nature and time of failure. The problem of dump slope stability gets aggravated during rainy season. The present paper discusses the effect of small plant on dump slope stability. Various types of plants (grasses and shrubs) have been taken for the study. The effects of vegetation on shear strength of dump mass have been determined by shear box tests. The sample of overburden dump has been brought from Northern Coalfields Limited (NCL), which is a

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subsidiary company of Coal India Limited and located at Singrauli, District Sidhi (MP). The area of NCL lies geographically between latitudes of 24°0′–24°12′ and longitudes 82°30′–82°45′, and comprises Gondwana rocks. The coalfield can be divided into two basins, viz., Moher sub-Basin (312 km^2) and Singrauli Main Basin (1890 km^2). The overburden rocks in this area are mostly medium to coarse-grained sandstone, carbonaceous shale and shaly sandstone. The studied area falls within the protected forest. The area is surrounded by open mixed jungle and dense mixed jungle from west, the north and the east and agriculture land on the southern side [16–18].

2. Shear strength of dump mass

The roots of smaller plants are massive and fibrous, thus can bind the upper layer of the dump mass. It modified the properties of dump material by adding the apparent cohesion. The shear strength is the most important parameter in stability analysis of dump slopes. Therefore, assessing of the shear strength with reasonable accuracy is a very important in analysis of the dump stability. A new composite material (dump mass and roots of plants) forms when plants are grown in the dump material. Testing of the vegetated dump mass is complicated and tedious process as it requires large sample size having sufficient roots in the sample. The laboratory shear box instrument (LSBI) has been designed and fabricated to evaluate the shear strength of large sample of dump mass with vegetation. The samples of dump mass having small plants roots could be prepared either in the laboratory or in situ condition. However, in the present paper the sample has been prepared in the laboratory and tested.

2.1. Laboratory shear box instrument (LSBI)

Fig. 1 shows the laboratory shear box instrument (LSBI). It has been in three parts, namely shear box, frame and loading device. Measuring devices have been also been integrated to the system for measuring the load. Shear box has been kept in cubical shape having two parallelepipeds, each having the size of 0.3 m × 0.3 m × 0.15 m. The lower part of the box has the top open, whereas, the upper part has the top and bottom opened. A square plate having the size of internal dimensions of the shear box has been placed on the top of the sample. It has been used to apply the normal load on the sample. The open part of the box has been forced to slide over bottom box so that the material fails at the interface between two parts. The shear box containing the sample has been kept at the lower level where as hydraulic ram is kept at higher level of the frame. The hydraulic ram has been attached in such a way that it applied horizontal forces at the upper shear box. The lower shear box has been firmly secured with frame by nuts and bolts, whereas the upper shear box is free to move.

2.2. Sample preparation and testing

The dump material has been brought from large open cast coal mines. It contained mainly sandstone and shale along with soil. The samples have been prepared in the wooden boxes (3.0 m × 0.3 m × 0.3 m). The roots of the grasses and shrubs have penetrated in the broken dump material and reinforced it. The wooden boxes have been dismantled carefully and samples have been cut into pieces with the help of a saw to prepare the specimen of the size 0.3 m × 0.3 m × 0.3 m, as shown in Fig. 2.

Another box has been made by a thin iron sheet of the same dimensions as that of samples. It has been kept open from the bottom. The open end of the box has been put on the sample in such a way the sample is covered all sides except the bottom. An iron sheet has been placed at bottom end of the box by lifting the box slightly. This arrangement has been done to protect samples while moving in the laboratory or in situ condition. The sample has been put carefully into the lower shear box which is clamped to the frame. The upper shear box has been put over the lower shear box, and the upper half of sample fits into the upper shear box. Horizontal force has been applied to the upper shear box until sample fails in shear. Various steps of the testing are depicted in Fig. 3.

3. Results of experimental tests

The results of various tests are tabulated in Tables 1 and 2. The cohesion of dump mass (without vegetation) is 9.4 kPa and internal friction angle is 33°. The bulk density is obtained 18 kN/m^3

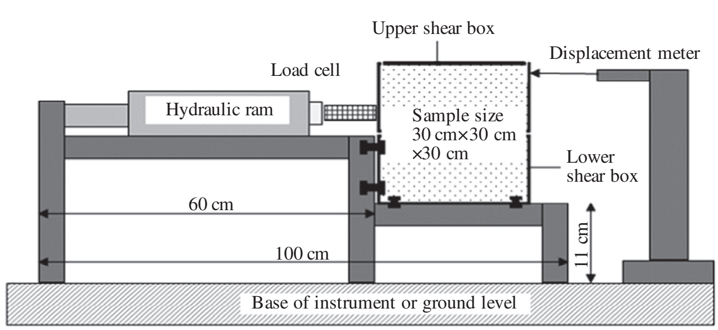

Fig. 1. Laboratory shear box instrument (LSBI).

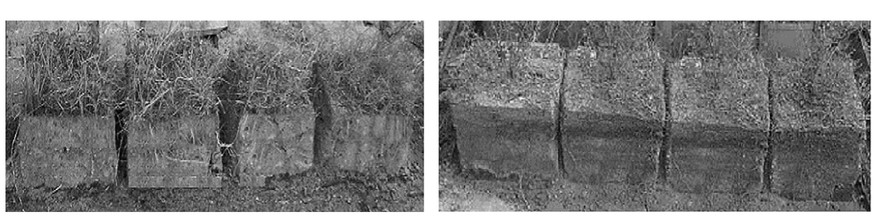

Fig. 2. Preparation of samples for shear strength test for grasses and shrubs.