ABSTRACT

India is the third largest producers of coal in the world with 89% of production coming from open cast coal mines. Open cast mining operation involves excavation of overburden (OB) material comprise of waste rock and barren materials that must be excavated to access the coal seams. The heavy earthmoving machineries such as draglines, shovels and dumpers are used to excavate the overburden materials. For the year 2019-20, the open cast coal production and OB removal was about 572.092MT and 1154.327Mm³ respectively with stripping ratio (ratio of OB material quantity to coal quantity) of 2.02. Majority of OB material is backfilled to the de-coaled area as internal dump and remaining is dumped outside of the mine as external dump.

Materials forming these dumps vary from silt and clay size (<75μm) to coarse grained soil particles (>75μm) including sands and gravels as well as large size cobbles (150-300mm) and boulders (>300mm). The OB dumps in most of the open cast coal mines are usually formed by end dumping method which results in formation of dumps with relatively low density and where the outer slope is just stable under the static loading conditions at angle of repose of 37-38°. The materials are subjected to wide range of environmental and climatic changes including erosion, ageing, wet dry cycles, seasonal temperature fluctuations and cyclic loading due to earthquakes, machine movement. These process results in degradation of strength properties of geomaterials and fragment sizes resulting in generation of fines.

The preparation of large-sized dumps is becoming a challenging task for the mine management from two important perspectives. First, the limited availability of surface leasehold land for dumping materials and the second, associated problems of slope stability with the increasing heights of dumps due to increase in stripping ratio. Any instability in the dump can affect the production rate and safe mining operations. Hence, slope stability study of dump needs to be carried out.

For the design and stability analysis of dumps, reliable and direct measurement of shear strength of OB materials has always been limited by the scale of the available testing equipment. There is lack of available data on representative OB materials and mine planners could no longer rely on experience-based models to establish design criteria with confidence. These necessitates a detailed geotechnical characterization of the dump materials forming the
dumps and assessment of the shear strength properties by testing representative samples under field load conditions.

Therefore, the objective of the research was to resolve uncertainties regarding shearing behaviour of existing and planned high dumps and to provide advice on determining reliable shear strength parameters for geotechnical design. To achieve this, a large scale sampling and testing was carried out from a wide range of 165 pits locations across 3 large coal fields, namely Ib valley, Talcher area of Mahanadi Coalfields Ltd. and North Karanpura area of Central Coalfields Ltd.

The geotechnical characterizations indicates that there is extreme spatial variation of particles in a dump mass. Younger dumps have comparably lesser fine contents (<75μm) than aged dumps. It is also found out that presence of coarse gravel (20-80mm) contributes approximately 50% of the mass of dump material which classifies the dump material as coarse-grained gravel (IS 1498-1970). Testing the coarse gravel material in conventional small direct shear machine doesn’t yield actual strength properties and scalping OB materials to match the constraints of standardised laboratory equipment, will result in an inaccurate estimation of strength properties.

The scale effects on apparatus size implies that there will be a minimum direct shear machine (DSM) size, in terms of specimen, shear box volume and load capacity that can be considered for the representation of in-situ state. To address these scale affects, a large direct shear machine (LDSM) of normal and shear load capacity of 2500kN each and box size of 1000mm×1000mm×1000mm is designed and developed at CMPDI, Ranchi. Using LDSM, maximum particle size ($D_{\text{max}}$) up to 80mm can be tested for direct shear as per ASTM D3080(98).

A total of 119 direct shear tests were performed on LDSM to assess the shear behaviour of representative OB materials. For these tests, test conditions were varied to acknowledge the scale effect arose due to size of the particle, shear box size and high stresses. Hence, in these tests, two separate specimens of $D_{\text{max}} \leq 25$mm and $D_{\text{max}} \leq 80$mm and two different shear box size of 1000mm×1000mm×1000mm and 300mm×300mm×300mm were considered. In accordance with insitu stresses, normal stresses were also varied from 108kPa to 6000kPa during testing. Tests results show that for similar materials (i.e., $D_{\text{max}} \leq 25$mm) when tested in DSM and LDSM, DSM tend to overestimate the shear strength upto 7%. However, when
comparing $D_{\text{max}} \leq 25\text{mm}$ results of DSM with LDSM results on representative materials (i.e., $D_{\text{max}} \leq 80\text{mm}$) at insitu normal stress, shear strength parameters improve by as high as $\sim 33\%$. This indicates that there will be a minimum test specimen size and a minimum test normal stress, that should be considered technically acceptable for simulating a shear surface within a high dump constructed of coarse OB materials.

Tests conducted under high normal stresses shows a non-monotonic pattern with three distinctively identified linear zones referred as tri-linear shear strength envelope. Depending on the normal stresses, the cause of shearing failure in these zones are rearrangement and sliding in Zone 1, rubbing and rolling over in Zone 2 and chipping and sliding in Zone 3. A regression analysis was performed to describe this behaviour of OB material under high stresses and a relationship between applied normal stress and shear stress based on particle shape and gradation is proposed using power law.

The strength parameters obtained from the DSM and LDSM are used in the stability analysis and probabilistic modeling for internal and external dumps of the coal mines to find out the factor of safety variance and suggest optimal dump height. Invariably for all cases, the LDSM test results has reported higher FoS when compared to that of DSM by a factor of 1.5 times approximately. Thereby it is evident that DST underestimates the stability of the dumps due to load and scaling limitations.

The probability analysis was carried out for different bench angles $37.5^\circ$ to $40^\circ$ and heights of external dumps (90m, 120m and 150m) and internal dumps (150m, 180m, 210m and 240m), the results indicate that the height of external dumps can be safely enhanced upto 150m from ground level and whereas for internal dumps the height can be enhanced upto 210m safely.