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Characterization of Shear Strength Properties of Spoil Dump Based on their Constituent Material

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Abstract

The shear strength and thereby the stability of spoil dump depends upon the nature and distribution of the constituent materials present in it. In a coalmine spoil dump, the constituent material generally consists of various proportions of sand, clay, sandstone and shale in Indian geo-mining scenario. In order to estimate the strength parameters, namely cohesion and angle of friction of overburden material, samples from two opencast coalmines located in the eastern part of India were collected and studied. A total of 176 tests, i.e. 11 set of test at 4 different normal load on sandstone-shale, sandstone-clay, shale-clay and sand-clay mixtures (11 × 4 × 4) were performed using small direct shear box at their near optimum moisture content. The shear strength parameters, i.e. cohesion and friction angle of the mixtures were found to be highly influenced by the proportion of cohesive ingredients (clay) with steep curve when compared to that containing non-cohesive material (sandstone and shale).

Keywords: overburden material, shear strength, coalmine, direct shear box test, clay content. compaction.

INTRODUCTION

Geotechnical engineers often come across earth materials having wide spatial variability. Among many types of mixed earth materials, the overburden (OB) found in coalmines is a high volume material to be handled around the globe. During excavation of coal a massive volume of overburden to the tunes of billions of tones per annum is generated in India alone [1]. Traditionally, these materials are disposed in the most efficient and least costly manner possible by dumping in spoil/waste dumps in the close proximity to the mines in order to limit the haulage cost. The dumping operations of overburden materials have not received due attention in terms of stabilization, monitoring and maintenance. Although, maintaining the stability of OB plays an important role in ensuring safety and productivity in the mines, these dumps have not been characterized or studied extensively because it is thought to have little significance on the overall profitability. Inability to accurately predict the geotechnical parameters used for basic planning and design has resulted in collapse of many existing dump slopes. Lack of scientific planning due to unavailability of proper testing equipment to accommodate the absolute material size of overburden dumps have resulted in a vague understanding of the stability of many existing and failed OB dump slopes. This nature of heterogeneity in mine waste dumps materials generally causes an overestimation or underestimation of their geotechnical properties that may affect the design of optimal configuration of dumps. Therefore, disposal of these coarse OB wastes, in highly populated and industrialized area requires special attention with proper planning. Precise determination of shear strength values, both cohesion and friction angle is critical to the design of dump slope [2]. Several studies have been conducted by various researches [2-8] on the behaviour of mixed earth material that give a clear indication on the importance of shear strength properties. Apart from the shear strength properties, a host of other factors such as amount and nature of clay minerals, particle size distribution, void ratio, dry unit weight, moisture content, hydraulic permeability, compaction, consolidation etc. also influence the behaviour of the whole soil-rock matrix [9-12]. Improving stability of overburden material by other stabilization measures such as eco-restoration, vegetation or mixing with fly ash have been studied by many researchers [13-16]. This technical paper characterizes the shear strength properties of overburden material of Indian coalmines and describes how it changes with the variation in the constituent materials of overburden dumps.

BACKGROUND

Surface mining over the years has become the backbone of Indian coal mining industry due to its economic advantage due to high production potential and better safety compared to those of underground mines. In exploitation of a sub-surface coal deposits, a significant proportion of non-coal material is required to be excavated, which involves multiple layers of top soil and other sedimentary rocks. Top soil having a different proportion of sand, clay, silts, gravel, rock-soil aggregates and overburden material containing rocks of sedimentary formations like shale, sandstone with different mineralogical compositions are excavated and removed while opening up new opencast mines [17].

From preliminary observation on the stratigraphy of the coal formation or the borehole log data of associated mines in Indian geo-mining condition, it may be estimated that the overburden material primarily consists of shale and sandstone. As the primary constituent materials in a waste dump are shale and sandstone, the changes in particle sizes due to grain crushing causing generation of clay may result in a change in the shear strength properties of the OB dumps. Based on the assumption that shale somehow behaves like clay, and sandstone behave like sand when crushed or found in degradable form, the behaviour of overall mixed material can be estimated. From the abovementioned assumption, if the key physico-mechanical properties of standalone shale and sandstone, and also their combinations are assessed at different geo-environmental conditions, it might be possible to predict the behavior of the spoil dumps. Therefore, in order to obtain the behaviour of mixed OB material, a number of laboratory mixed samples containing shale, sandstone, clay and sand in various proportions were prepared and tested. The test results from laboratory study and their interpretation are presented in the section below.

CHARACTERIZATION OF STUDY AREA

Samples were collected from waste dumps of two mines located at different geographical locations namely Kusunda-Alkusa opencast project of Bharat Cocking coal Ltd. (BCCL), and Sonepur Bazari of Eastern Coalfield Ltd. (ECL). Kusunda opencast mine is situated in Jharia coalfield (Jharkhand) with a leasehold area of 349.47 Ha. It is located 4-5 Km west of Dhanbad railway station at a latitude of 23° 44’ 12.73” N to 23° 46’ 28.02” N and longitude of 86° 22’ 54.6” E to 86° 25’ 38.5” E. Sonepur Bazari opencast mine, one of the largest producer of coal in the state of West Bengal (WB), is situated in Raniganj coalfield.

The overburden (OB) in both the mines consists of a layer of top-soil followed by an alternate layer of shale, sandstone or both mixed together. The top most layer of material above a coal seam mostly consists of soft to hard soil, organic material, gravel and are mainly suitable for excavation by shovel with or without blasting.

LABORATORY TESTS

Sample collection

To study the behaviour of shale and sandstone with different composition of cohesive material, clay of moderate cohesive strength and low friction angle was chosen from a mines situated in Bankura district in the state of West Bengal, located within latitudes 22°46´ and 22°34´ and longitudes 86°30´ and 87°29´. The main composition of the sedimentary overburden material is shale and sandstone. The shale obtained from the mine waste dumps are found to be soft and are mainly black in color with the presence of fissile and laminated structures in the forms of layers, which is a common property of shale. The sandstone formations found in the mine are light in color with fine to coarse grained distributed over different locations of the bedding plane. The samples for laboratory tests were prepared by mixing the OB material and clay, and tested following Indian standard testing procedures.

Index properties

To get a preliminary idea about the characteristics of overburden material, a set of index tests such as Atterberg’s limit, slake durability, moisture content, specific gravity, etc. following Indian standard testing procedure were performed. The sandstone are fine grained, weathered, brown to pale white in color with a specific gravity of 2.56. The shale collected is weathered and black in colour with a specific gravity of 2.58. The consistency of clay sample was determined from Atterberg’s limit tests and the clay was classified to be of CL type with intermediate plasticity as per Indian standard soil classification system.

Direct shear box testing

A number of direct shear box (6 cm × 6 cm) tests were carried out as per Indian Standard testing procedure IS: 2720 Part 13-1986 [18] with composite mixtures of river sand, cohesive clay (kaolin), crushed sandstone and shale. The content of each ingredient was varied from 0% to 100% at an interval of 10% and tested their near optimum moisture content (OMC). A total of 176 samples, i.e. 11 set of test at 4 different normal load containing sandstone-shale, sandstone-clay, shale-clay and sand-clay mixture (11 × 4 × 4) were tested using small direct shear box at a moisture content close to their OMC. The shear box tests were conducted at 4 different normal loads of 0.5 kg/cm2, 1.0 kg/cm2, 1.5 kg/cm2 and 2.0 kg/cm2 respectively for each sample type after being compacted by the normal load for a time period of 8 hours. A pictorial representation of sample collection and laboratory testing is given in figure 1 below.

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Figure 1: Sample collection and testing using small direct shear box

The shear strength parameters, namely cohesion and friction angle of pure clay (kaolin) respectively hold the value of 41 kPa and 13.5 degrees with specific gravity of 2.58. The optimum moisture content (OMC) and maximum dry density (MDD) of the mixed material was obtained through Standard Proctor compaction test following Indian standard testing procedure IS: 2720 Part 7-1980 [19].

ANALYSES AND RESULTS

The results obtained from the laboratory experiments are plotted against their constituent material composition in the mixture. The cohesion and friction angle values are plotted against four mixtures: sand-clay, sandstone-shale, sandstone-clay and shale-clay in varying proportion as shown in figure-2 through figure-4.

As the range of variation of cohesion and friction angle for pure sand and clay are wide apart, the curve showing cohesion versus clay content and friction angle versus clay content follow a steep curve. However, for all kind of mixtures there is a similarity in the trend they follow. The cohesion of the mixed materials increases generally with the increase in cohesive content in the mixture, here clay or shale, which can be clearly observed from Fig. 2. However, the friction angle of the mixed material decreases with increase in clay or shale content in the mixture. For the sandstone-shale mixture, the shear strength properties do not change much, which may be due to less variation of cohesiveness of these materials.

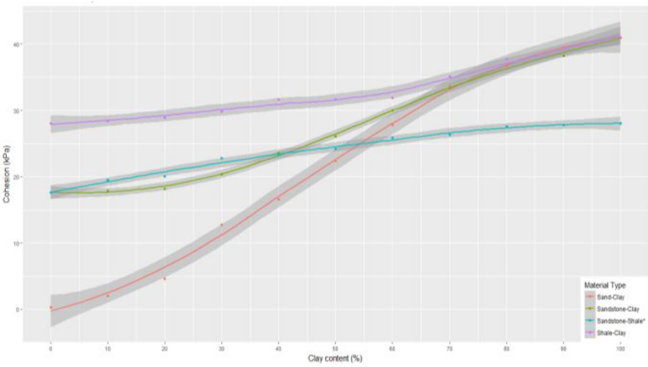

Figure 2: Cohesion vs clay (*shale) content of mixed materials

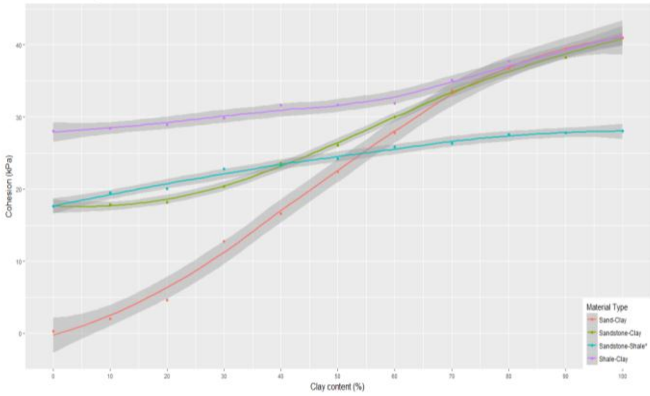

Figure 3: Friction angle vs clay (*shale) content of mixed material

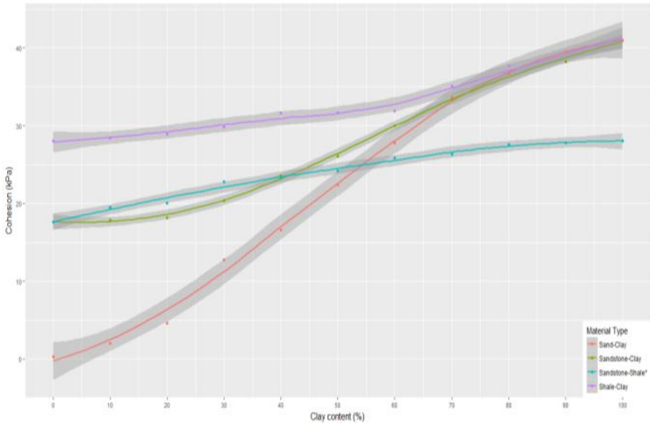

Figure 4: Cohesion versus friction angle of mixed material

The plot of cohesion versus friction angle of all the mixtures tested show somewhat similar trend. But, there is little fluctuation in the trend for mixture of sandstone-shale and shale-clay. Due to wide range variation of shear strength values, cohesion and friction angle, for both pure sand and clay, the cohesion-friction angle varies over long range and are negatively correlated with each other, which is obvious.

SUMMARY AND CONCLUSION

The mixed material found in the interface of top soil and coalmine overburden material is very complex in terms of both material type and its size distribution. The materials properties of these overburden rocks or rock-soil mixture are most likely to change due to repeated exposure to weathering and particle crushing during loading and hauling process. The crushed sandstone material being formed by similar kind of sand grains during sedimentation possesses characteristics somewhat similar to that of sand, while the weak, weathered and crushed materials of shale tends to behave like a clay material formation when subjected to watery condition. With this laboratory study on mixed earth rock observed in Indian coalmine waste dumps, where the properties of all major constituent materials are taken into consideration may be helpful in the estimation of the key physico-mechanical properties of coalmine waste dumps. From the experimental study of various combination and types of mixed materials mentioned above, the following conclusions may be drawn.

1) The shear strength properties, both cohesion and friction angle of mixed sand-clay, sandstone-clay, shale-clay, and sandstone-shale, almost follow similar kind of pattern when plotted against their constituent material in the mixture.
2) The cohesion of the mixture increases with increase in clay or shale content for all type of mixtures tested. However, the range of variation, i.e. upper and lower limit of pure sand and pure clay, the snad-clay curve follows a steep curve, while for a mixture of sandstone-shale and shale-clay, the range of variation is small and remains flat throughout.
3) The inverse proportionality of cohesion with the friction angle holds true for all materials except sandstone-shale and shale-clay mixture, which shows wide fluctuation in the curve.

These properties altogether do not give any significant result in estimation of shear strength or compaction parameters, as these materials are associated with high heterogeneity and spatial variability. It may be helpful in predicting the behaviour of spoil material in Indian coalmines. The experimental values are, however, liable to change with a change in material properties and surrounding geo-environmental factors. Further characterizations of other properties of the mixed material and identifying the key variables that may influence the physico-mechanical properties can help geotechnical and mining engineers largely.

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