GEOTECHNICAL CHARACTERISATION AND STABILITY ANALYSIS OF COAL MINE OVERBURDEN DUMPS IN INDIA

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by

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CERTIFICATE

This is to certify that the thesis entitled, **"Geotechnical Characterization and Stability Analysis of Coal Mine Overburden Dumps in India"**, being submitted by **Mr. Sravan Kumar Gara** to the Indian Institute of Technology Delhi, for the award of **'Doctor of Philosophy'** is a record of the bonafide research work carried out by him under my supervision of this thesis, which to the best of my knowledge has reached the requisite standard. The material contained in this thesis has not been submitted in part or fully to any other university or institute for the award of any degree or diploma.

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ABSTRACT

India is the third largest producers of coal in the world with 89% of production coming from opencast coal mines. Opencast 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 opencast coal production and OB removal was about 572.092MT and 1154.327Mm^3 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 opencast 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_{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_{max} ≤25mm and D_{max}≤ 80mm 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_{max} ≤25mm) when tested in DSM and LDSM, DSM tend to overestimate the shear strength upto 7%. However, when comparing D_{max} ≤25mm results of DSM with LDSM results on representative materials (i.e., D_{max} ≤80mm) at insitu normal stress, shear strength parameters improve by as high as ~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° to 40° 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.

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
BMAC	Billiton Mitsubishi Alliance Coal
CCL	Central Coalfields Limited
CIL	Coal India Limited
CMPDI	Coal Mine Planning and Design Institute
CMR	Coal Mine Regulations
CNL	Constant Normal Load
CNS	Constant Normal Stiffness
CSIRO	Commonwealth Scientific and Industrial Research Organization
DAQ	Data Acquisition System
DEM	Discrete Element Method
DFSI	Differential Free Swell Index
DGMS	Director-General of Mine Safety
DGMS	Director General of Mines Safety
DSA	Direct Shear Apparatus
DSM	Direct Shear Machine
DST	Direct Shear Test
ECL	Eastern Coalfields Limited
ED	External Dump
EIA	Environmental Impact Assessment
EMP	Environment Management Plan
FEM	Finite Element Method
FSI	Free Swelling Index
GSD	Grain Size Distribution
GSI	Geological Survey of India
HEICO	Hydraulic Engineering Instruments Co.
ICDD	International Centre for Diffraction Data
ID	Internal Dump
IPD	In-Pit Dumping
IS	Indian Standard

ISO	International Organization for Standardization
JCS	Joint Wall Compressive Strength
JRC	Joint Roughness Coefficient
LDSM	Large Direct Shear Machine
LDST	Large Direct Shear Test
LEM	Limit Equilibrium Method
LVDT	Linear Variable Differential Transformer
MCL	Mahanadi Coalfields Limited
MDD	Maximum Dry Density
MECL	Mineral Exploration Corporation Limited
MoEF&CC	Ministry of Environment, Forest and Climate Change
MS	Mild Steel
MTPA	Million Ton Per Annum
NC	Normally Consolidated
NCL	Northern Coalfields Limited
OB	Overburden
OBD	Overburden Dumps
OBM	Overburden Material
OCM	Opencast Mine
OCP	Opencast Project
OMC	Optimum Moisture Content
QTMR	Queensland Transport and Main Roads
SCCL	Singareni Collieries Company Limited
SD	Standard Deviation
SECL	South-Eastern Coalfields Limited
SWCC	Soil-Water Characteristic Curve
TS	Technical Specification
UCS	Unconfined Compressive Strength
UM	Underground Mining
WCL	Western Coalfields Limited
XRD	X-Ray Diffraction

LIST OF NOTATIONS

D_{max}	Maximum partcile size
FoS	Factor of safety
P_f	Probability of failure
P	Probability of event
L	Length
D	Diameter or edge size of shear box
u_a	Pore air pressure
u_w	Pore water pressure
i	Average angle of deviation of particle displacements from the direction of the applied shear stress (saw-tooth angle)
c	Cohesion
c′	Effective cohesion
2c	Initial crack length (according to Griffith's theory)
A,b	Shape factors
R	Equivalent particle Roughness
S	Equivalent particle strength
n	Porosity
d	Horizontal displacement
d_{50}	Particle size equivalent to 50% passing
D_{50}	Mean particle size
D_{60}	Particle size corresponding to 60% passing
D_{30}	Particle size corresponding to 30% passing
Cu	Uniformity coefficient
Cc	Coefficient of gradation
T	Specimen thickness
W	Direct shear box width
E	Young's modulus of intact geo-material
V	Specimen volume
G	Specific gravity
CL/ML/OL	Clayey / silty / organic material with low plasticity
CI/MI/OI	Clayey / silty / organic material with intermediate plasticity

CH/MH/OH	Clayey / silty / organic material with high plasticity
I_p	Plasticity index
W_L	Liquid limit
k	Permeability
I	Moment of inertia
I	Factor depending upon the importance of structures
SW	Well graded sand
SP	Poorly graded sand
GP	Poorly graded gravel
A_c	Corrected cross sectional area
ΔV	Change in volume of the material
ΔH	Change in horizontal displacement
R^2	Correlation coefficient
F_o	Seismic zone factor for average acceleration spectra
S_a/g	Average acceleration coefficient for an appropriate natural period and damping of structure
T	Natural period of vibration for earth fill structure
G	Modulus of rigidity
τ	Available shear strength
τ_a	Actual shear stress
τ_p	Peak shear strength
τ_f	Shear stress at failure
ϕ	Angle of shearing resistance
ϕ'	Angle of effective shearing resistance
ϕ_b	Angle indicating the rate of strength increase with respect to matric suction
ϕ_s	Secant friction angle for the applied normal stress
ϕ'_s	Secant friction angle for a given effective normal stress
ϕ'_u	Angle of interparticle sliding friction
ϕ'_g	Angle of geometric interference
ϕ'_r	Residual friction angle
ϕ'_b	Mobilized angle of friction of OB dump material
ϕ'_a	Mobilized angle of friction of laboratory specimen

$\Delta\phi$	Difference in friction angles
σ_n	Normal stress
σ'_n	Effective normal stress
σ_c	Unconfined compressive strength
σ_f	Normal stress at failure
σ_t	Uniaxial tensile strength
σ_1	Major principal stress
σ'_3	Effective minor principal stress
γ	Unit weight
γ_{bulk}	Bulk unit weight
γ'	Effective unit weight
α	Surface energy per unit area of the crack surface
μ_w	Pore water pressure
μ_a	Pore air pressure
δ	Deflection
Å	Angstrom
λ	Wavelength
θ	Glancing angle of X-ray beam or diffraction angle
ε	Shear strain
ε_f	Failure horizontal strain
α_0	Basic horizontal seismic coefficient
β	Coefficient depending on the soil foundation system
α_h	Horizontal seismic coefficient
ρ	Mass density