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Investigation of Shear Strength Parameters of Highwall Rock Slopes and Overburden Dump Mass in Opencast Coal Mines

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Abstract

India is one of the largest producers of coal in the world with 89% of production coming from opencast mines. Opencast mining operation involves excavation of waste rock i.e. rock formations overlying the coal seams and coal from highwall. Majority of waste rock is back-filled to the de-coaled area and remaining part is dumped outside quarry as external dump. To minimize the amount of rock excavation from highwall, a steep slope of highwall needs to be maintained. The backfilling of waste rock in a limited space of de-coaled area and also outside quarry makes the backfilled dump and external dump slope steeper. Hence, slope stability study of highwall and waste dump embankment needs to be carried out for maintaining safety and economics of the mine. Determination of representative values of shear strength parameters of waste dump and highwall which is not covered in standard soil mechanics and rock mechanics text book is a pre-requisite for stability analysis. This paper presents the methodology of determining representative values of shear strength parameters of highwall and waste embankment.

Keywords: *Shear Strength Parameters, Highwall, Overburden Dump, Slope Stability.*

1. Introduction

India has reached the forefront of world coal scene, ranking 3rd in total coal production. It is largely due to rapid increase in contribution from opencast coal mines (presently 89%). Limited space for mining activity and the general strip mining method usually practiced in these mines makes the highwall benches steep. Production from an opencast mine also generates huge volume of overburden waste rock. These overburden material is dumped in the form of heaps within the quarry as well as externally. The stability of these highwall slopes and overburden dumps is considered to be the prime concern of the opencast operators and planners due to its typical method of mining and simultaneous backfilling. The heavy earth moving machineries such as draglines, shovels & dumpers etc; excavates the blasted rock and dumps the same fragmented rock immediately in the earlier de-coaled area which is explained in figure 1. It is very much essential for this dump mass heaps to take as much as less space and at the same time be stable for both safety and economics of the mine. For the highwall slopes and the dump mass to be stable and consume least possible space of the quarry, a stability analysis has to be done so as to get optimum height and slope for both the highwall slopes and the dump mass. One of the most important input parameters for stability analysis is the shear strength values i.e. cohesion and angle of internal friction of the different rock types constituting the highwall and the heterogeneous dump mass. The heterogeneous dump mass is a mixture of almost all rock types overlying the coal seams. The internal dump embankment stands above interface material which is a slushy layer of crushed rock and coal submerged in water.

This paper presents different methodology and formulation of determining shear strength parameters of highwall, dump and interface material.

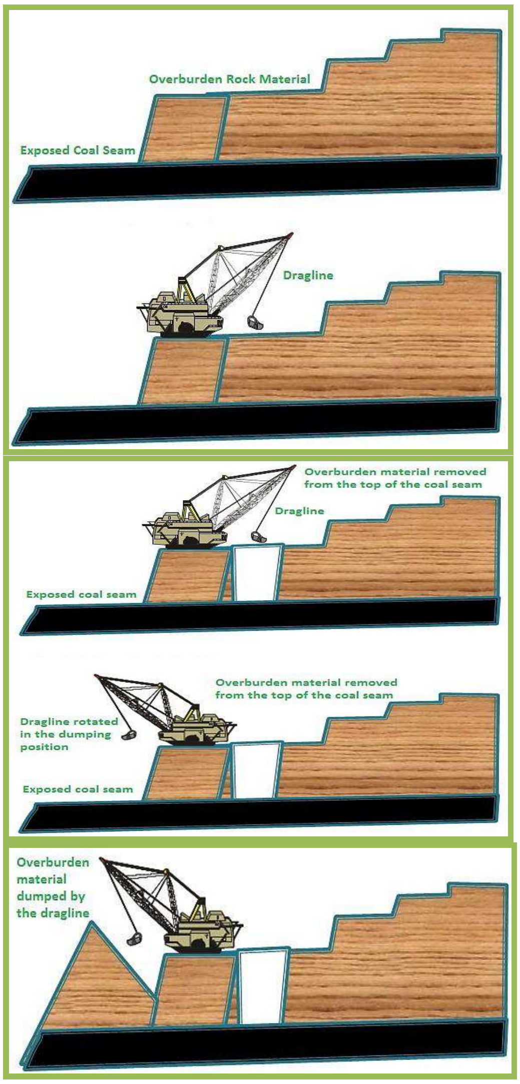

Fig. 1 Schematic diagram showing the process of overburden removal and subsequent dumping

2. Activities Involved in this Investigation

- ❖ Collection of highwall rock samples, dump and interface material from 19 opencast coal mines.
- ❖ Compaction of the dump and interface material collected (for the purpose of site simulation).
- ❖ Laboratory test to determine the shear strength parameters.
- ❖ In-situ determination of the shear strength parameters.
- ❖ Result generation.

2.1 Collection of Samples

Subheadings should be as the above heading “2.1 An amount of 150 Kg of both dump and interface material were collected each from 19 opencast minesviz. Jayant, Khadia, Bina, Nigahi, Dudhichua, Amlohri and Jhingurdah opencast mines of Northern Coalfields Limited, Madhya Pradesh. Umrer, Sasti, Gondegaon and Ghugus opencast mines of Western Coalfields Limited, Maharashtra. Dhanpuri open cast mine of South-Eastern Coalfields Limited, Madhya Pradesh. Block II and Konkaniopencast mine of Bharat Coking Coal Limited, Jharkhand and Sonepur Bazari opencast mine of Eastern Coalfields Limited, West-Bengal. Tadkeshwar and Surkha opencast lignite mine of Gujarat Mineral development Corporation, Gujarat. Gare Palma II opencast mine of Lanco Infratech Limited and Fatehpur East Coal Block, Chhattisgarh.
Apart from these rock samples constituting the highwall slopes were also collected from different sections viz. along transition planes (bedding planes) i.e. change of rock formations, along geological structures such as faults, joints etc. within the highwall slopes.

Fig. 2 Collection of sample from interface section of overburden dump

2.2 Compaction for Site Simulation of Dumps and Interface Material

The overburden dump masses in the mines are in immense load due to its own weight under the action of gravity. So, to simulate the field condition, the collected dump and interface material were individually compacted in large box shear apparatus. These materials were compacted at the level of stress actually existing within the dump mass as the dump material could only be collected from the dump surface during sampling.

These materials were compacted in the laboratory as per the principles of equivalent material modeling for simulation. For example, if the dump height is 50m and average bulk unit weight is 20KN/m^3, then the average compaction stress is 250 KN/m^2. In that case for simulation, dump materials were compacted in large box shear apparatus to the stress of 250 KN/m^2 before shearing.

2.3 Laboratory Tests

2.3.1 Laboratory Test for Dump and Interface Materials

Laboratory tests on the collected dump and interface samples for determination shear strength parameters were carried out in large box shear apparatus.

In the direct shear test, the failure of the compacted sample in shear is caused along a pre-determined plane. The normal load, strain and shearing force were measured directly during the test. It was also used to estimate the residual stress of the sample. The apparatus comprises of a square box (40 X 40 cm) divided horizontally into two halves. The box containing the sample is placed under water jacket in case of interface material and placed without water in case of dump material. This was then subjected to constant normal load while a horizontal force was applied till the sample failed along the juncture of the two halves. This was conducted for five different normal stresses ranging from 100KN/m^2 to 500KN/m^2 and on five different sets of samples, both of dump and interface material.

Fig. 3 Fig 3: Different stages of direct shear test being conducted in large box shear

Test Report 6/7/2011

Project Description		SetNo 1	
Test Type	Direct Shear	Specimen Description	
Project Id	GMDC	Specimen Id	Dump
Project Site	Tadkeshwar	Specimen Length(cm)	40
Soil Type	Dump	Specimen Width(cm)	40
Remarks	External Dump	Specimen Thickness(cm)	15
		Specimen Area(Sq.cm)	1600
Bulk Density(g/cc)	1.92	Specimen Volume(cc)	24000
Dry Density(g/cc)	1.74	Specimen Weight (g)	46000
Degree of Saturation(%)	-107.81	Water Content(%)	10
100% Saturation	-9.26	Specific Gravity	1.5
Void Ratio	-0.14	Sigma n (kg/sq.cm)	2
Porosity(%)	-16.16		

dHDisp (cm)	T (kg)	dVDisp(cm)	Corrected Area(sq.cm)	Tau Corrected (kg/sq.cm)	Sigma n (kg/sq.cm)
0.000	-6.0	1.658	1600.00	-0.01	2.00
0.075	290.0	1.676	1597.00	0.18	2.00
0.184	399.0	1.704	1592.64	0.25	2.01
0.295	472.0	1.709	1588.20	0.30	2.01
0.404	494.0	1.712	1583.84	0.31	2.02
0.513	507.0	1.714	1579.48	0.32	2.03
0.620	516.0	1.717	1575.20	0.33	2.03
0.726	533.0	1.717	1570.96	0.34	2.04
0.832	529.0	1.718	1566.72	0.34	2.04
0.938	530.0	1.719	1562.48	0.34	2.05

Fig. 4 A representative test report of direct shear test

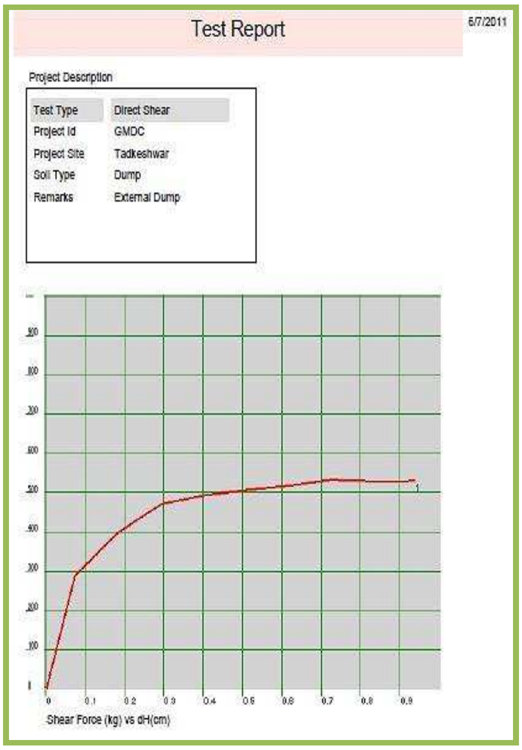

Fig. 5 A representative test graph of direct shear test

2.3.2. Laboratory test for intact rock cores and broken cores

In case of competent rock strata in the highwall, core drilling generates intact rock cores of diameter 50mm and length more than 150mm. These rock cores are tested in rock tri-axial testing machine for determination of cohesion and angle of internal friction. In case of rock masses traversed by various types of geological structures and plane of discontinuities; core drilling cannot generate intact rock cores. Hence, tri-axial testing and uniaxial testing cannot be done on these broken rock cores. These broken rock cores are subjected to point load test for determination of compressive strength along and across the plane of weakness. The point load test apparatus is primarily an index test for strength classification of rock material. But here, the test was used for indirect determination of shear strength parameters as follows;

i.e. $I_{s(50)} = P/D^2$

here;

P = Load at failure.

D = Diameter of the core (ideally).

Now for cores other than those with 50mm diameter, (P/D^2) was retained and multiplied by a size correction factor F.So, two strength indexes were derived;

Uncorrected strength; $I_S = P/D^2$

And, corrected strength; $I_{s(50)} = F(P/D^2)$ Where;

$F = (D/50)^{0.45}$

Based on test results, but including the tensile strength, a power law is the most relevant type of expression, i.e.

$\sigma_1 = A\ C_O\ [\sigma_3/C_O + T_O/C_O]^n$

Where;

σ_1 = Major principal stress.

σ_3 = Confining pressure.

A = Coefficient.

N = An index which depend on rock type.

Thus the values of σ_1 and σ_3 obtained from the above method and formulas were used to plot Mohr's circle, which in turn gave the values of cohesion and angle of internal friction.

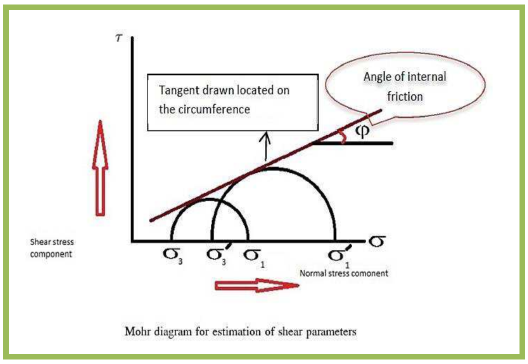

Fig. 6 Mohr's circle

2.4 In-situ determination of shear strength parameters

Presence of discontinuities such as folds, faults, joints and bedding planes etc. is responsible for extreme reduction in shear strength parameters of rock formations, which otherwise are quite high when determined in intact samples in the laboratory. For deduction of these reduced values of shear strength parameters, certain formulations are used.

The value of in-situ cohesion was evaluated by the formula;

$$K_m = \frac{K}{1 + \alpha \log_e \frac{H}{L}}$$

Where;

H = Total height of pit slope.

K = Cohesion of rocks in sample in wet condition (T/m^2).
L = Average spacing (m).
α = Co-efficient depending upon rock strength in sample, nature of cracks.

Table 1 In-situ evaluation of cohesion: Co-efficient table

Characteristics of Rock	Cohesion in monolith solid (Kg/cm^2)	Co-efficient (α)
Loose, compact and weak fissured sandstone-clay deposit, intensively weathered and fully kaolinized igneous rocks.	4 – 9	0.5
Compact sandstone-clay deposit having mainly vertical cracks.	10 – 20	2.0
Compact sandstone-clay deposit having mainly vertical cracks, intensively kaolinized igneous rocks.	30 – 80	2.0
Compact sandstone-clay deposit having developed inclined cracks, kaolinized igneous rocks.	30 – 80	3.0
Medium hard stratified rocks having mainly vertical cracks.	100 – 150 150 – 170 170 – 200	3.0 4.0 5.0
Hard rock having mainly vertical cracks.	200 – 300 > 300	6.0 7.0
Igneous hard rock having developed inclined cracks.	> 200	10.0

2.5 Results

2.5.1 Shear strength parameters of dump and interface material

In the following table the various parameters are;
C_1 = Cohesion of dump material.
C_2 = Cohesion of interface material.
Φ_1 = Angle of internal friction of dump material.
Φ_2= Angle of internal friction of interface material.

Table 2: Shear strength parameters

SlNo.	Name of the Mine	C_1(KN/m^2)	Φ_1 (°)	C_2 (KN/m^2)	Φ_2 (°)
1	Jayant	75	25	40	21
2	Bina	70	27	60	23
3	Khadia	75	30	58	29
4	Nigahi	65	28	40	21
5	Dudhichua	75	35	40	25
6	Amlohri	65	27	30	20
7	Sasti	50	18.5	30	13
8	Ghugus	75	19.5	55	18
9	Gondegaon	75	27	25	12
10	Sonepur Bazari	50	29	55	19
11	Block II	70	40	55	30
12	Konkani	62	40	57	29
13	Dhanpuri	45	25	40	20
14	Tadkeshwar	20	06	15	08
15	Surkha	30	13	20	08
16	Gare Palma II	75	25	40	21
17	Fatehpur East Coal Block	75	25	40	21

2.5.2 Shear Strength Parameters of Highwall Rocks

In Table 3 the various parameters are;
C_1 = Cohesion of highwall benches.
C_2 = Cohesion of silt.
Φ_1 = Angle of internal friction of highwall benches.
Φ_2= Angle of internal friction of silt.

Table 3: Shear strength parameters of highwall rock slopes of Umrer OCM

Sl No	Name of the Mine	C_1 (KN/m^2)	Φ_1 (^{o})	C_2 (KN/m^2)	Φ_2 (^{o})
1	Umrer	75	30	30	13

In the following table the various parameters are;
C_1 = Cohesion of bedding plane between quartzite and mudstone.
C_2 = Cohesion of coal.
Φ_1 = Angle of internal friction of bedding plane between quartzite and mudstone.
Φ_2= Angle of internal friction of coal.

Table 4 Shear strength parameters of highwall rock slopes of Jhingurdah OCM

Sl No	Name of the Mine	C_1 (KN /m^2)	Φ_1 (^{o})	C_2(KN /m^2)	Φ_2 (^{o})
1	Jhingurdah	100	30	26	27

Table 5: In-situ cohesion values for rock formations of Jhingurdah opencast mines

Sl No	Rock Formation	Cohesion (KN/m^2)	
		Laboratory Value	In-situ Value
1	Quartzite	10,000	26
2	Mudstone	20	1

3.0 Conclusion:

The stability of highwall comprising of benches and overburden dump heaps in an opencast mine is one of the most important and essential factor for safe and economic operation of the mine. Stability analysis of these highwall benches and overburden dumps requires generation of shear strength parameters i.e. cohesion and angle of internal friction.

Dump material comprises of a wide variation of soil particles with size less than 0.075mm to rock boulders of more than 1000mm. There is also wide variation of permeability, void ratio, porosity, optimum moisture content relative density and other geo-technical parameters. The stress condition also varies abruptly within the dump mass. Standard soil mechanics literature doesn't cover all the above aspects, due to heterogeneous properties of the dump mass. Shear strength parameters of such a heterogeneous masscan be generated in the laboratory by direct shear test in large box shear apparatus. Generation of the shear strength parameters in the laboratory requires collection of sample material (dump and interface material) from different sites and locations, simulation of site conditions on the sample. The simulation involves compaction of the sample to the actual site stress condition andmaintaining the water content equivalent to that present in the site.

In case of highwall stability, laboratory determined values of rock core (broken or intact) do not represent the actual strength of rock mass within the highwall. The rock mass comprises of joints, cracks, fault zones, shear planes and bedding planes due to which strength of actual rock mass is much less than the laboratory determined rock strength. The strength reduction due to presence of above structural weaknesses within rock mass has been discussed in this paper.

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