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Inspection based slope stability engineering and management with greening benefits in coal mines

1.0 Introduction

Slope stability is a constant concern in surface coal mines. The challenges are becoming more and more complicated with every passing day as the land for dumping, particularly outside the mine area, is becoming premium and unavailable. For a large part of the mining history, all over the world, the maintenance and management of slope stability has been neglected with disastrous results. Slope failures are still very common. While the unprecedented natural calamity led slope failures are not in the hands of the mine's management, the containment of damage by design and protection of human lives and asset by intervention are to a large extent, within the control of the management. Importantly, as outsourcing and job contracting is taking hold in the owner led mining activities one large casualty is the lack of inspection by the owner management. A sound inspection regime in the mine can bring down the catastrophic consequences to a large extent, the efforts and preparations for which are detailed in the paper.

1.1 Regulatory requirements of Slope Stability Control and Management:

Ministry of Environment and Forest, India mandates for environment protection of OB dumps and cites the following (http://www.indiaenvironmentportal.org.in/files/html/Environment_Clearance/7402_2014_1_23_Jan_2014_1101050831DumriOCPECletter.pdf):

1. The individual dump should have a maximum slope and an overall slope not exceed a certain value.
2. The external dump should have stretches of retaining wall at suitable locations.
3. The wall should be constructed with suitable height and top surface. The wall will have weep holes to drain out water to the garland drain/sediment pond.
4. The back-filled areas should be levelled to match with adjoining ground level.
5. The completed dumps and the back-filled areas should be afforested in a planned way to increase their stability.
6. Overburden in most cases are not contaminated. However, composition of the leach ability of heavy metals of overburden and low grade ore dumpsites are very important.
7. The top soil prior to drilling and blasting should be stacked at designated area surrounded by embankment to prevent erosion.
8. The overburden and top soil dumps should be stabilized by plantation and anchoring with coir nets/blankets.
9. Garland drains (size, gradient and length) around the safety areas and low lying areas and sump capacity shall be designed keeping 50% safety margin over an above the peak sudden rainfall and maximum discharge in the area adjoining the mine sites. Sump capacity shall also be provided adequate retention period to allow proper settling of silt material. Catch drains and siltation ponds of appropriate size shall be constructed to arrest silt and sediment flows from soil, OB and mineral dumps.
10. The water so collected shall be utilized for watering the mine area, roads, green belt development, etc. The drains shall be regularly desilted and maintained properly.
11. Garland drains (size, gradient and length) and sump capacity shall be designed keeping 50% safety margin over and above the peak sudden rainfall and maximum discharge in the area adjoining the mine site.
12. Sump capacity shall also provide adequate retention period to allow proper settling of silt material.
13. Dimension of the retaining wall at the toe of the dumps and OB benches within the mine to check run-off and siltation shall be based on the rainfall data.

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Further, Chapter X of Coal Mines Regulations, 2017,106. says all mechanized opencast working. - (1) In all mechanized opencast workings, the precautions specified in sub-regulation (2) to sub-regulation (6) shall be observed. (2) Before starting a mechanized opencast working, the owner and agent of the mine shall ensure that the mine, including its method of working, ultimate pit slope, dump slope and monitoring of slope stability, has been planned, designed and worked as determined by a scientific study and a copy of the report of such study has been kept available in the office of the mine: Provided that in case of mines where such a study has not been made, it shall be the responsibility of the owner and agent to get the said study made within one year from the date of coming into force of these regulations. (3) The owner, agent and manager of every mechanized opencast mines shall ensure that the recommendations made in the report of scientific study referred to in sub-regulation (2) are complied with.

1.2 CMR 2017 108. Spoil-banks and dumps

While removing overburden, the top soil shall be stacked at a separate place, so that, the same is used to cover the reclaimed area.

1. The slope of a spoil bank shall be determined by the natural angle of repose of the material being deposited but, in any case, shall not exceed 37.5 degrees from the horizontal: Provided that wherein any mine, a steeper slope of spoil bank has been recommended as a result of scientific study by any scientific agency or institution, having expertise in slope stability, the Regional Inspector may, by an order in writing and subject to such conditions as he may specify therein, permit steeper slope of the spoil bank.
2. Loose overburden and other such materials from opencast workings or other rejects from washeries or from other sources shall be dumped in such a manner that there is no possibility of dumped material sliding.
3. Any spoil bank exceeding 30 meter in height shall be benched so that no bench exceeds 30 meter in height and the overall slope shall not exceed 1 vertical to 1.5 horizontal.
4. The toe of a spoil-bank shall not be extended to any point within 100m of a mine opening, railway or other public works, public road or building or other permanent structure not belonging to the owner.
5. A suitable fence shall be erected between any railway or public works or road or building or structure not belonging to the owner and the toe of an active spoil bank so as to prevent unauthorized persons from approaching the spoil-bank.
6. No person shall approach or be permitted to approach the toe of an active spoil bank where he may be endangered from material sliding or rolling down the face.
7. Adequate precautions shall be taken to prevent failure of slopes of the spoil

2.0 Brief description of the mine

Yekona-I and II block is located in WaroraTahsil of Chandrapur district of Maharashtra State and is named after nearby Yekona village.The area is bounded by latitudes N 20°13'42" to 20°16'10" N and longitudes E 78°55'00" to 78° 58’ 30" and is covered by Survey of India Topo Sheet No.55L/15 & 55L/16.Yekona block is an under developed region of Chandrapur district. The Delhi Madras Grand Trunk railway line passes from the East of the Yekona-I and II block. The nearest railway station is Warora, situated at 7 km distance, S.E of the block. The Nagpur Chandrapur road is about 7 km to the East of the Yekona-I and II block. The block can be approached by a fair-weather road from Warora to Majri via Warora. This road passes through the eastern part of the block and joins Nagpur-Chandrapur road at Warora. Nagpur and Chandrapur townships are located at a distance of 110 km and 52 km from the block, respectively (Table 1).

Table 1: Geo-technical mining parameters.

	Parameters	Yekona I	Yekona II
1	Av. Thickness of seam (m)	9.24	9.94
2	Gradient of seam	1 in 7 to 1 in 14	1 in 4.8 to 1 in 8
3	Depth (m): Min. Max.	 30 160	 25 150
4	Av. Strike length (m) At surface At floor	 1700 1400	 3800 3200
5	Average Dip-Rise width (km) a) On floor b) On surface	 1.2 to 2.0 1.5 – 2.4	 0.60 0.87
6	Area of the Quarry (Ha) a) On floor b) On surface	 214.70 354.50	 238.64 339.74
7	Total mineable reserves (Mt)	25.04	32.81
8	GCV (kCal/kg) (without dilution at each contact point)	4714 (G-9)	5053 (G-8)
9	Total volume of OB (mm^3)	225.71	226.78
10	Average stripping ratio (m^3/t)	9.01	6.91
11	Annual mine target (Mty)	1.00 to 1.25	1.25 to 1.50
12	Life of the mine	25	24

3.0 Geology

3.1 Geological succession

The general stratigraphic sequence and a typical borehole section of the Yekona-I opencast mine is shown in Fig.1. Clay bands just above the coal seam or in between the

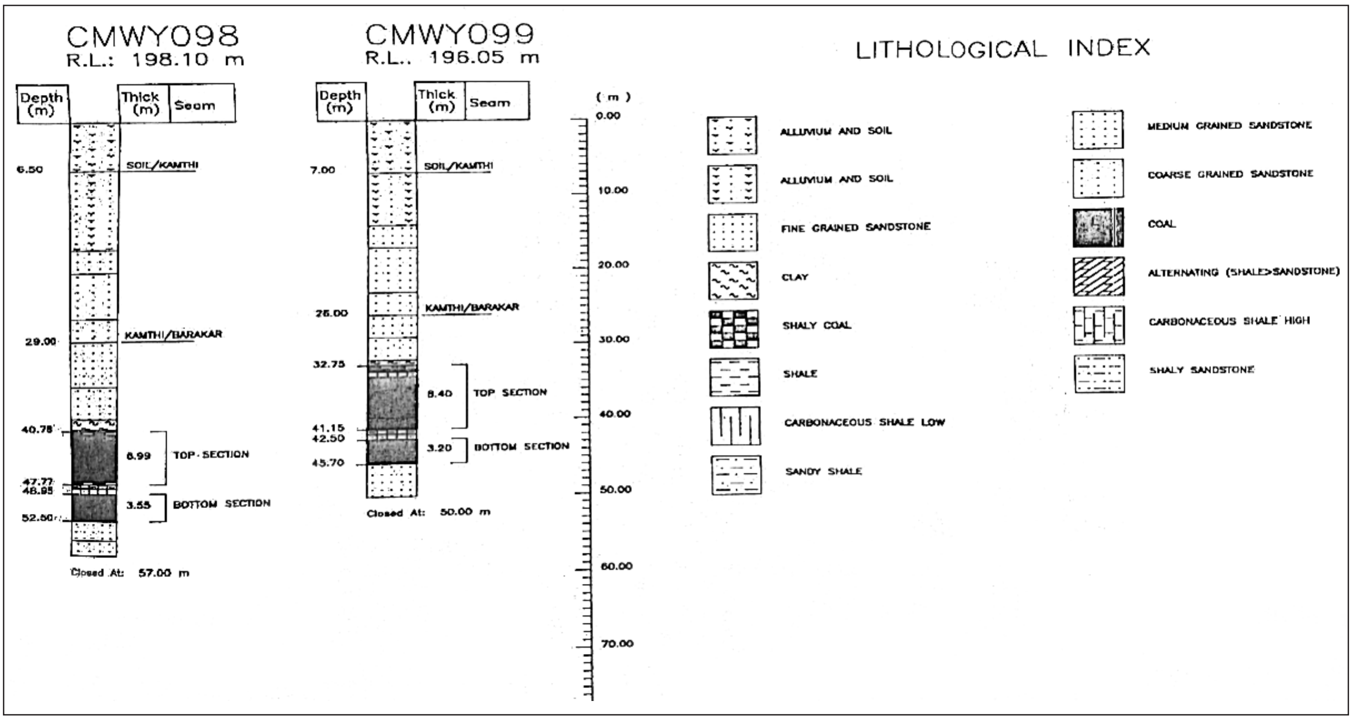

Fig.1: Lithology of borehole CMEY098 and CMWY099.

sandstone beds provide a potential weak plane for sliding in some cases (Jhanwar & Thote, 2011, 44:635-640). The presence of clay minerals results in the rapid decrease in cohesion during rainfall, as loss of surface frictional contact between the grains due to high absorption of water. The presence of clay minerals gives more plasticity to the soil which is one of the most important cause of slope failure. (Behera et.al, 2016, 88:725-735).

3.2 Strike and Dip

Yekona – I block

Coal seam dips towards SE in the Western part and towards East in the Eastern part. The gradient of seam is 1 in 8 (60) to 1 in 17.5 (30) in the Western part and 1in 6 (90) to 1 in 8 (60) in general in the Eastern part with local flattering. The strike of coal seam in the Western part is NE-SW whereas; in the Eastern part it is N-S with minor swing.

Yekona – II block

The general strike of the coal seam as determined from the floor contour plan of composite seam is WNW-ESE dipping SSW however local swings in strike also observed in the area. The dip of the formation in the block is in 1 in 4 to 1 in 7.5; a) Middle part dip is 11.3° due SSW. b) Western part dip ranges from 7.6° to 11.3° due SSW. c) Eastern part dip is 14° due SSW (Gradient 1 in 4)

3.3 Faults

Yekona – I block

A total of 10 faults (F1 to F10) have been interpreted in Yekona-I block based on the evidences such as reduction in seam thickness/parting floor difference in adjacent boreholes.

Table 2: Details of Faults in Yekona-I Block.

Fault No	Extent of fault (km)	Trend	Throw		Evidence
			Direction	Amount	
F1-F1	1.50	NW-SE	SW	95m-130m	Difference in floor level of coal seam in boreholes CMWY-84, 11, 73 in up thrown side and CMWY-82, 13 in downthrown side.
F2-F2	1.00	NW-SE	SW	0-20m	Difference in floor level of coal seam in boreholes CMWY-67, 27, inup thrown side and CMWY-11, 73 in downthrown side.
F3-F3	1.20	NW-SE	SW	0-20m	Difference in floor level of coal seam in boreholes CMWY-28, 39 and MWM-77 in downthrown side CMWY-10 in up thrown side.
F4-F4	1.17	NW-SE	NE	0-15m	Difference in floor level of coal seam in boreholes CMWY-10 in downthrown side. And CMWY-66, 55 on up thrown side.
F5-F5	0.45	NNW-SSE	WSW	10-15m	Difference in floor level of coal seam in boreholes CMWY-79, 5I in up thrown side and CMWY-71 in downthrown side.

Fault No	Extent of fault (km)	Trend	Throw		Evidence
			Direction	Amount	
F6-F6	1.30	NW-SE	SW	60-140m	Absence of Composite Seam in CMWY-24 & 63
					Difference in floor level of coal seam in boreholes CMWY-3, 29, 34, MWM-10 in up thrown side and CMWY-33, 32, 52, 26 in downthrown side.
F7-F7	0.350	WNW-ESE	NNW	0-15m	Absence of Bottom Section in CMWY-51.
					Difference in floor level of coal seam in boreholes CMWY-74, 61 in up thrown side and CMWY-3, 64 in downthrown side.
F8-F8	2.50	NW-SE	SW	200m	Absence of Composite Seam in its up thrown side.
F9-F9	1.65	NW-SE	SW	10-20m	Difference in floor level of coal seam in boreholes CMWY-38, 56, MWM-12 in down thrown side and CMWY-9 in upthrown side.
F10-F10	1.40	NW-SE	SW	30-40m	Absence of Top Section and roof of Bottom Section is faulted in CMWY-58.
					Floor of Bottom Section is faulted in CMWY-54.

Table 3: Details of Faults in Yekona-II Block

Fault no.	Extent of fault (km)	Trend	Throw		Evidence
			Direction	Amount	
F1-F1	1.550	NW-SE	NE	125m	Motur Formation intersected in BH (CMWY-95,107,126, MWM15) on the downthrown side of the fault F1-F1 lies in juxtaposition to middle and upper part of Barakar
					Formation in Borehole CMWY-91, 118 & 123 MWM-36
F2-F2	0.170	NE-SW	NW	0-4m	Bottom section is faulted in CMWY-55
F3-F3	0.210	NE-SW	NW	0-4m	Bottom section is faulted in CMWY-55
F4-F4	1.035	WNW-ESE	SW	0-18m	Top section in CMWY-114 and bottom section floor is faulted in MWM-38. Based on FRL differences in boreholes CMWY-105 & 122 in the up throw side and CMWY-113 in the downthrown side.
F5-F5	0.990	NE-SW	NW	20-30m	Based on FRL difference in borehole MWM-29 & 39 in upthrow side and CMWY-104 & 124 in the downthrown side

Yekona – II block

A total 5 number of faults (F1 to F5) have been interpreted in Yekona-II block based on the evidences such as reduction in seam thickness/parting floor difference in adjacent borehole. Details are shown in Table 3.

It was observed that when the workings reached within 10–30 m of the faults with strike parallel to the slopes, signs of the potential instability started appearing. The opencast mine workings should therefore be laid in such a way that the fault planes do not strike parallel to the benches (Jhanwar & Thote, 2011, 44:635-640).

3.4 Fold

There is no fold encountered in this area, as reported.

3.5 Dyke

There is no reported presence of dykes.

3.6 Physiography

Almost entire area of the block is covered with black cotton soil. The area exhibits a gently undulating topography with general slope towards south-west. The altitude of area ranges between 188.10m (reduced level of borehole MWM32) and 204.42m (reduced level of borehole MWM25). Surface contour for the area are available at 1 m interval. The main drainage of area is controlled by Wardha river, which is flowing south-easterly and form western limit of block. Some small seasonal *nallah* are also flowing in south-westerly direction in the block area to join Wardha river.

3.7 Climate

The study area falls under subtropical climate zone experiencing hot summer and mild winter. In summer, general maximum and minimum temperature is around 43°C and 28°C respectively. However, rarely the summer temperature shoots up as high as 47°C in May/June. In winter, general maximum and minimum temperature is around 29°C and 12o C respectively. However, minimum temperature seldom falls to as low as 7°C in December/January. Generally, monsoon starts by mid-June and continues till September, August being the month of highest rainfall. Nowadays, there are instances of occasional medium to heavy rainfall even during non-rainy seasons. The annual rainfall (1984-2017) collected from WCL, Majri Area GM office is furnished in Table 4.

TABLE 4: THE ANNUAL RAINFALL DURING THE PERIOD 1984-2017

Year	Annual Rainfall (mm)	Year	Annual rainfall (mm)
1984	846	2001	1349
1985	953	2002	893
1986	1992	2003	1043
1987	747	2004	631
1988	1392	2005	1761
1989	882	2006	1560
1990	1980	2007	1638
1991	1033	2008	1520
1992	1158	2009	1106
1993	1107	2010	2210
1994	2466	2011	1939
1995	1836	2012	1606
1996	852	2013	----
1997	712	2014	1349
1998	931	2015	1786
1999	1158	2016	2113
2000	1158	2017	1205

TABLE 5: PROGRESSIVE MONTHLY RAINFALL AND PEAK RAINFALL

Year	2017			2018		
Month	Progressive rainfall (mm)	Max. (on a particular date)	Min. (on a particular date)	Progressive rainfall (mm)	Max. (on a particular date)	Min. (on a particular date)
June	69	20	0	124	31	0
July	270	98	0	457	95	0
August	91	28	0	187	48	0
September	176	56	0	203	133	0

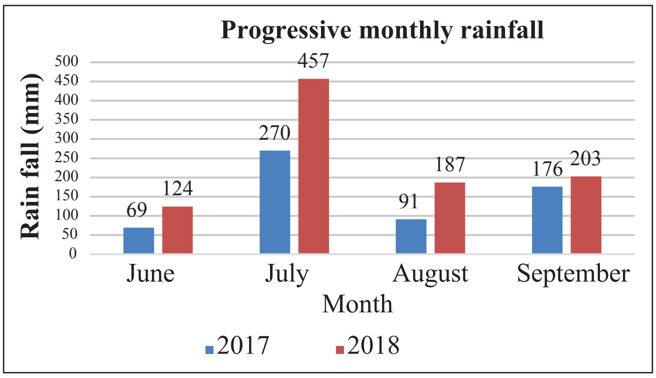

Fig.2: Graph showing progressive monthly rainfall.

It thus indicated that slope failure occurred, when there was a rainfall of an order of 70–130mm during the last 8 days of failure including the day of failure. A cumulative rainfall of an order of 150–500 mm was found to be associated with either the development of the first signs of instability (in general) or an actual failure, where other extraneous factors played a major role in initiating the slope failures. A heavy rainfall of an order of 80 mm causes the transition of a slope from a steady state to an actively unstable state (Jhanwar & Thote, 2011, 44:635-640). In Table 4 rainfall data is given.

3.8 SURFACE HYDROLOGY

The area is principally drained by the Wardha river, flowing from north-west to south-easterly, located about 1 km west of the block. This river is fluent and perennial. During summer the discharge dwindles considerably. Beside Wardha river, Daiwal river and some local *nallahs* are flowing through this area, which finally join the Wardha river. A few water conservation structure/schemes such as bunds, canals are also available in this area.

3.9 HYDROGEOLOGY

Groundwater occur below water table in the inter-granular pour space of sand stone in semi-consolidated sediments of Gondawanas and also in weathered basalts and their secondary porous structure. Generally, sandstone horizons in Gondawanas serve as aquifer material and the impervious shale/clay beds act as aquicludes. The weathered/secondary zones in Kamptee and Barakar formations near a fault zone act as potential aquifer. The water seepage in the current working position at 180RL is shown in Fig.4. The delineation of the aquifers system is given in Table 6.

Table 6: Type of aquifer in and around Yekona II Block

<table>
<tr><th colspan="2">Hydrogeological unit</th><th>Formation</th><th>Thickness ranges (m)</th></tr>
<tr><td colspan="2">Sallow aquifer/ Unconfined aquifer (potential aquifer)</td><td>Kamptee sandstone</td><td>10.00-39.50</td></tr>
<tr><td rowspan="2">Deeper aquifer (Low to medium potential aquifer)</td><td>Aquicludes</td><td>Motur clay/shale/ sandstone/coal seam</td><td>3.36-183.75</td></tr>
<tr><td>Semi confined aquifer</td><td>Barakar sandstone (considered above coal seam)</td><td>10.97-106.40</td></tr>
</table>

The projected hydrogeological parameter of aquifer in Kamptee/Barakar formations are as follows:

- Hydraulic conductivity : 2.2m/day
- Storage coefficient : 1.57×10^{-4} to 1.1×10^{-3}
- Specific yield : 0.05

4.0 Loose dump details

The proposed height of overburden dumps has been envisaged as 90m above ground level. Presently now here in Majri area, dumping is done above 60m. Hence, it is proposed in the prefeasibility report to conduct a slope stability study, for which capital provision has been made. Moreover, it is proposed to remove a thickness of 2.5m of black cotton soil from 120m wide trench along the periphery of external dump for better stability of dump. Out of total 456.03 Mm^3 OB (452.49 Mm^3 from quarry and 3.54 from trench cutting), 133.50 Mm^3 OB will be accommodated in external OB dump and balance 322.53 Mm^3 will be dumped in decoaled void of the two quarries. Thus, 29.27% of total OB will be dumped externally and 70.73% OB will be accommodated in the internal dumps. The dump capacities of different OB dumps are tabulated in Table 7.

Table 7: Available dump capacity

	Type of dump	Capacity (Mm^3)
1	External dump	133.50
2	Temporary dump to be re-handled	43.83
3	Internal dump	322.53
	Total	456.03

The height of overburden hard dump can be made up to 90m keeping the benches 20m in height and width 25m with bench slope angle 35°. The height of OB black soil dump can be made up to 45m keeping the benches 10m in height and 15m width with bench slope 30°.

The loose or broken dumps of the mine consists of top BC soil and rocky overburden. BC soil dump is kept separately. In the mine there is one BC soil dump and another rocky overburden dump. Both these dumps require separate analytical treatment to determine slope stability parameters.

5.0 Mine bench details

The mine has started just more than a year before i.e. in 2016-17, thus it has only five BC soil and mixed soil benches till now which is shown in Fig.3. However, the coal seam is exposed currently in mid of October 2018. The details of existing benches are given in Table 8.

Table 8: Existing mine bench in the mine. (As on date 15/10/2018)

Existing bench	Height	Width	Slope
Bench 1	3	Top	50
Bench 2	3	9	55
Bench 3	3	9	55
Bench 4	3	9	45
Bench 5	3	9	50

The proposed bench height and width of the mine benches are 10m each with a bench slope angle of 70° and overall slope angle of 35°. These bench parameters are taken on account of average geotechnical parameters (cohesion (c), internal angle of friction (φ) and unit weight (γ)) of slope material.

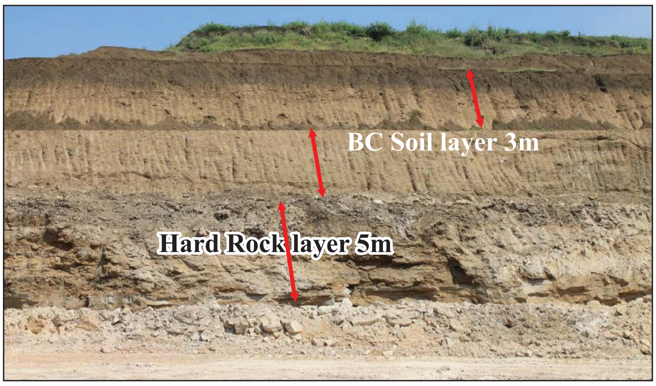

Fig.3: Showing BC soil and hard OB layer (as on 15/10/2018).

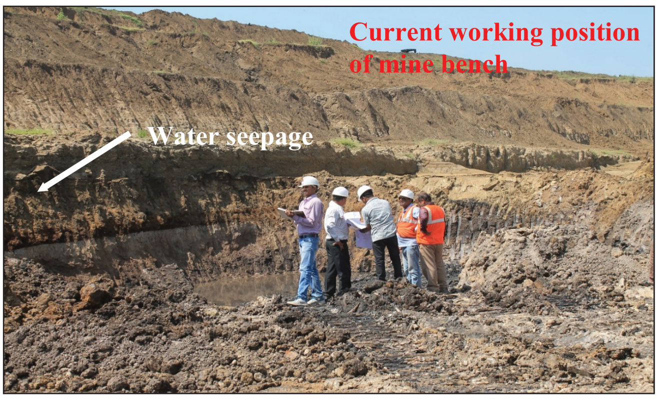

Fig.4: Current working portion of mine. (as on date 15/10/2018)

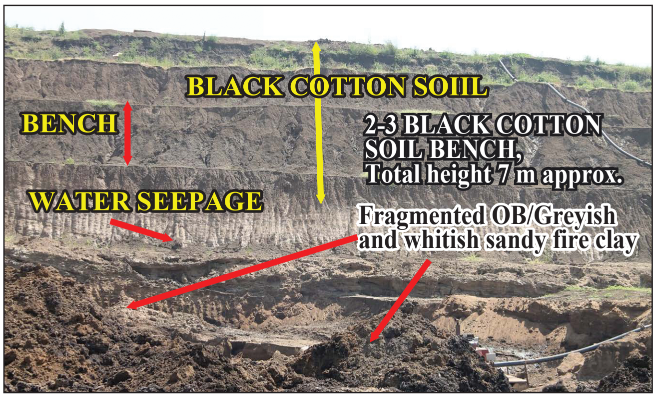

Fig.5: No. of benches (as on 15/10/2018).

6.0 Slope failure related problems in the mine

The slope failure in the mine is mainly induced by rain, the rainfall causes erosion of slope surface which contributes to slope failures, the rill and gully erosion are mostly encountered in this area. A type of rill and gully erosion is shown in Fig.6.

Slope failure can be controlled by reducing the length of the slope and the slope angle. However, the slope angle for broken material will finally assume the natural angle of repose, and hence the slope angle is a material property dependent on the size distribution of materials. However, we can control the height of slope. The other methods of reducing the slope failure due to water seepages are to reduce the influence of water are terracing, construction of diversion ditches and garland drains. Terracing is the technique of converting a slope into a series of horizontal step-like structures with the aim of

1. Controlling the flow of surface runoff by guiding the runoff across the slope and conveying it to a suitable outlet at a non-erosive velocity;
2. Reducing soil erosion by trapping the soil on the terrace;
3. Reducing the impact of slope failures by controlling the volume of slippage, and
4. Creating flat land suitable for plantation;
5. Terracing helps prevent the formation of rills, improves soil fertility through reduced erosion, and helps water conservation.

The three main types of terrace are bench, level or contour, and parallel or channel. We will discuss two varieties in detail.

Bench terraces are particularly suitable where marked seasonal variations exist in the availability of water. The approach consists of converting relatively steep land into a series of horizontal steps running across the slope. In the surface mines bench terraces with drain and ditches are applied (details later). These terraces can be constructed by dozing the existing slope and creating the terrace having a mild negative slope towards the diversion ditch as well as by constructed simply digging out the clayey soil, or they can be reinforced with locally available mud, stone, or brick. The terraces help conserve moisture during the long dry season, which is especially important where there are sandy and loam types of soil, and they help to slow and drain away runoff during the heavy rainfall monsoon season, which also helps counteract the tendency for sliding. There are three main types; outward, level, inward sloping terraces, inward is the most suitable for steep slopes because they guide the surface runoff towards the hillside rather than down the slope. Rainwater can be drained from outward sloping terraces along a ditch constructed along the toe of the river.

The main aim of contour terraces is to retain water and sediment. Contour terraces are similar to bench terraces, with the major difference that the terrace is formed along the contour, so that runoff flows across but not along the terrace. In addition, the terrace edge is planted with trees, small plants, and grass to stabilize it and trap sediment.

Fig.6: Showing erosion in mine OB dump (as on 15/10/2018)

7.0 Slope stability analysis

7.1 Factor of safety Calculation Methods

Circular failure

Circular failure criteria have been used for broken overburden and BC soil dumps. Under soil and rock dump slope conditions, one or more of the discontinuities normally defines the slide surface. However, in the case of a closely fractured or highly weathered rock, a strongly defined structural pattern no longer exists, and the slide surface is free to find the line of least resistance through the slope. Observations of slope failures in these materials suggest that this slide surface generally takes the form of a circle, and most stability theories are based upon this observation.

Plane failure

Plane failure in a rock slope takes place where a block of rock has slid on a single plane dipping out of the face. Plane failure criteria have been used for the solid coal and solid overburden slopes. In order for this type of failure to occur, the following geometrical conditions must be satisfied:

A. The plane on which sliding occurs must strike parallel or nearly parallel (within approximately ±20°) to the slope face.
B. The sliding plane must "daylight" in the slope face, which means that the dip of the plane must be less than the dip of the slope face, that is, $\beta<\psi_f$.
C. The dip of the sliding plane must be greater than the angle of friction of this plane, that is, $\beta>\varphi$.
D. The upper end of the sliding surface either intersects the upper slope, or terminates in a tension crack.
E. Release surfaces that provide negligible resistance to sliding must be present in the rock mass to define the lateral boundaries of the slide. Alternatively, failure can occur on a sliding plane passing through the convex "nose" of a slope.

Once the physical, technical and geotechnical parameters are obtained then the slope stability calculations begin. Considering different types of slope failure like circular failure, wedge failure, plane failure and toppling failure, the factor of safety is calculated on the basis of cohesion, pore water pressure, water saturation and internal angle of friction. For a slope here we have considered a minimum factor of safety of 1.0 at 100% saturation level, i.e., this is the minimum level of safety against slope failure even when the soil has reached 100% saturation, due to rain or water seepages. Normally, before 90% saturation, liquefaction of the slope can begin and so the values of slopes of broken material are calculated with 90% saturation.

7.1.1 Broken rock/soil benches

7.1.1.1 For overburden rock dump

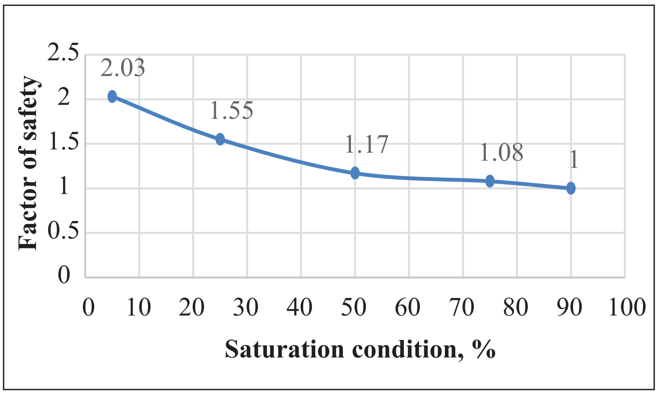

Fig.7: FOS of overburden for different saturation level.

Table 9: FOS calculation parameters for OB dump benches/proposed height and width of dump benches

Cohesion, kPa	Angle of internal friction	Height of bench, meter	Width of bench, meter	Bulk density, kN/m^3	Average FOS	Saturation condition %	Comments
65	24	20.0	25.0	24	2.03	5	
61	23	20.0	25.0	24	1.55	25	
57	21.5	20.0	25.0	24	1.17	50	
48	20	20.0	25.0	24	1.08	75	
45	**19**	**20.0**	**25.0**	**24**	**1.00**	**90**	Factor of safety is likely to decrease substantially during heavy rain situations. In these slopes terracing, ditches, garland drains and horizontal pipe drains will be applied as shown in Figs. 18-35

Table 10: FOS calculation parameters for BC soil dump

Cohesion, kPa	Angle of internal friction	Height of bench, meter	Width of the bench, meter	Bulk density, kN/m^3	Average FOS	Saturation condition %	Comments
55	30	10.0	15.0	18	3.12	5	
45	27	10.0	15.0	18	2.44	25	
35	25	10.0	15.0	18	1.90	50	
30	22	10.0	15.0	18	1.49	75	
20	20	10.0	15.0	18	1.11	90	Factor of safety is likely to decrease substantially during heavy rain situations. In these slopes terracing, ditches, garland drains and horizontal pipe drains will be applied as shown in Figs. 17-25

7.1.1.2 Black cotton soil dump

Cohesion being less and due to granular shapes of particles, the BC soil dumps would characteristically have less factor of safety. Moreover, disturbance by digging and transportation, would encourage loss of organic material and fine particulates,when exposed to the Sun and rain under different episodes.

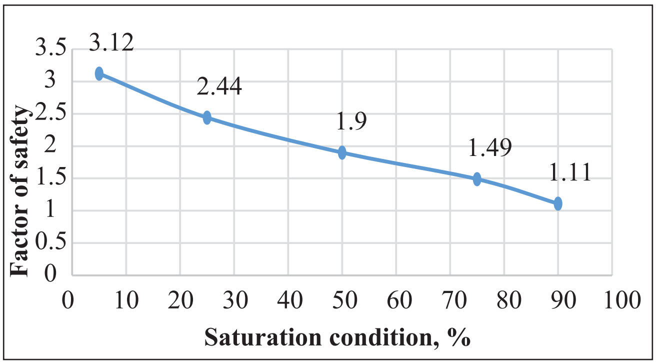

Fig.8: FOS of black cotton soil for different saturation level

7.1.2 Solid mine benches

Solid mine benches in the mine are 3 types: coal benches, rocky overburden benches and BC soil plus rocky overburden benches. Cohesion being higher than broken rock, it will have high FOS when dry and free of major geological disturbances and when, there is a good confinement. Depending on the material property, porosity and permeability, presence of water, geological features like slip plane, and localized vertical load due to heavy machinery, solid bench slopes can become unstable.

7.1.2.1 Solid overburden bench

In the intact overburden bench, rainfall led saturation of the overburden material, though continuously reduces the factor of safety, but does not decrease normally beyond the acceptable limit. However, formation of cracks, presence of loose soil like material can substantially reduce the factor of safety. During the rainfall seasons of June to September, particularly the Slope Stability Team would ensure that if the overburden shows signs of slope failures as given in sections 9 and 12 of this report, it must propose appropriate actions to the mine management, to save men and property.

TABLE 11: FOS CALCULATION PARAMETERS FOR MINE WORKING OB BENCH

Cohesion, kPa	Angle of internal friction	Height of bench, meter	Width of bench, meter	Bulk density, kN/m^3	Average FOS	Saturation condition %
102	24	5.0	7.0	26	3.49	5
102	24	5.0	7.0	26	3.39	20
102	24	5.0	7.0	26	3.08	30
102	24	5.0	7.0	26	2.91	35
102	24	5.0	7.0	26	2.81	40

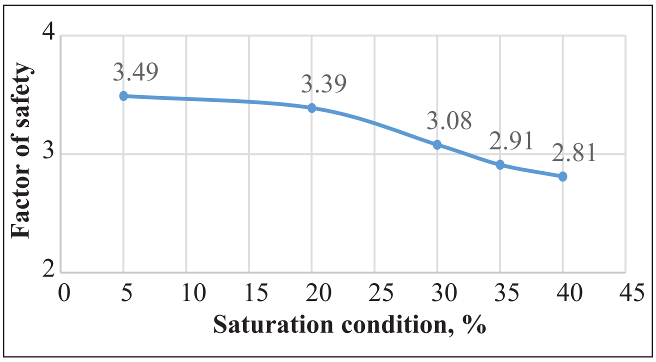

Fig.9: FOS of mine bench for different saturation level

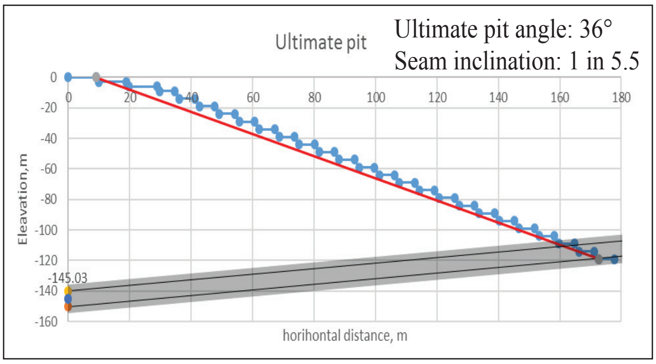

Fig.10: Ultimate pit of the mine

7.1.2.2 Solid coal bench

The values are given in results and discussions.

8.0 Results and discussions

One the basis of the slope stability calculations the following operating values of the parameters are considered:

Place	Cohesion kPa	Angle of internal friction	Bulk density, kN/m^3	Average FOS	Saturation condition (%)	Height of bench, meter	Width of bench, meter	Comments
OB broken dump	45	19	24	1.00	90	20.0	25.0	In these slopes terracing will be applied. Movements will be measured by total station. Other measures can be found in the recommendations
BC soil dump	20	20	18	1.11	90	10.0	15.0	In these slopes terracing will be applied. Movements will be measured by total station. Other measures can be found in the recommendations

Place	Cohesion kPa	Angle of internal friction	Bulk density, kN/m^3	Average FOS	Saturation condition (%)	Height of bench, meter	Width of bench, meter	Comments
Mine OB Bench (hard rock)	102	24	26	2.81	40	5.0	7.0	For these slopes poles will be used for measurement of movement by total station.
Mine Coal Bench (hard)	35	15.3	13.6	1.83	20	10.0	12.0	The bench width will be always more than the bench height, preferably by 2.0m. For these slopes poles will be used for measurement of movement by total station.
BC Soil benches/ fragmented benches	39	28	19	2.06	40	3.0	9.0	For these slopes poles will be used for measurement of movement by total station. Other measures can be found in the recommendations

9.0 Slope failure indications

The slope stability team under the mine management must look into the indicators as mentioned below on a regular basis and report the same to the mine management for appropriate actions.

An indicator is defined as a sign, a state or a contributing factor that points out or suggests that the rock mass may be prone to damage or failure. Usually, indicators suggest that the properties of the effected rocks are different from the surrounding rock mass. In general, potential slope failure is indicated by geotechnical features or mining operational factors.

A. Geotechnical indicators may include:

1. Structural features such as faults, shear zones or slickensides planes (Fig.11),

Fig.11: A slicken sided plane facilitating failure of a slope. In the interfaces of weak and jointed rocks with soil in contact with a massive block of rock with sharp surfaces, the failure can take place along the sharp surface, when wet (library picture, not own and not of the mine, Courtesy: Szwedzicki T. (2003)).

2. Geological disturbance in the form of folds and dykes.
3. Cracks on a slope occurs with creeps. It is a horizontal crack that appears at the top of a slope where parts of the soil and rock layer break away from the main slope, also known as a tension crack.
4. A change in the mechanical properties of the rock mass.
5. Layers of weak soil or rocks.
6. Poor ground conditions, e.g. jointed blocky ground.
7. Movement across faults or sets of joints.
8. Seismic activity.
9. An increase in water inflow or a change in the water table. Bulging ground appearing at the base of a slope or retaining wall, which indicates increasing water pressure. The water needs to be drained.
10. Water breaking above the ground surface in areas near a slope that is called ponding. It indicates water from above and at the foot of the slope is not flowing along proper channels and pools in unexpected areas.
11. Water appearing at the base of a slope also indicates ponding.
12. Floor heave at the toe of the slope in open pits.
13. Wall slumping in open pits (Fig.12).
14. Bulging (outward and upward) near the toe of slopes.
15. Cracks near the crest of the slope (Fig.13).
16. Fences, retaining walls, utility poles or trees tilting or shifting from their original positions are signs of ground movement. It can move very slowly and is classified as a form of slope failure, called a creep.
17. Cracks appear on the ground or in the foundation of houses, buildings and other structures. However, cracks sometimes develop due to reasons not related to slope movement so look around for other tell-tale signs.
18. Collapsed pavement, fallen rocks and earth, land movement and mudflow are among the indications that may lead to larger trouble later.
19. Sunken or down-dropped road beds can indicate ground movement.
20. Widening cracks appear on the ground or on paved areas such as streets or driveways.

Fig.12: Slumping of weak rock at the bottom of an open pit. The cracks show local failures have occurred in the area and can spread (not own and not of the mine, Courtesy: Szwedzicki T. (2003)).

B. In addition to geological indicators, analysis of operational indicators can draw attention to possible rock mass structural damage. Such operational indicators include:

1. Blast damage.
2. An accumulation of water in nearby excavations.
3. Steep slopes in open pits.
4. Undercut slopes.
5. Unbalanced surface mining.

Fig.13: Progressive opening of cracks at a periphery of an open pit. If the cracking spreads even after filling, the signs are dangerous and must be monitored (not own and not of the mine, Courtesy: Szwedzicki T. (2003)).

6. Little or no mechanical soil control like terracing or construction of ditches.
7. Little or no greening and mulching activities.

10.0 Recommendations on the basis of the study

10.1 Method of work

One the basis of the studies we recommend the following working height of different benches and slopes in the mine:

Places	Cohesion kPa	Angle of internal friction	Bulk density kN/m^3	Average FOS	Saturation condition (%)	Height of bench, meter	Width of bench, meter	Comments
OB broken dump	45	19	24	1.00	90	20.0	25.0	In these slopes terracing will be applied. Movements will be measured by total station. In these slopes terracing, ditches, garland drains and horizontal pipe drains will be applied as shown in Figs.18-25
BC soil dump	20	20	18	1.11	90	10.0	15.0	In these slopes terracing will be applied. Movements will be measured by total station. In these slopes terracing, ditches, garland drains and horizontal pipe drains will be applied as shown in Figs.17-25
Mine bench (OB hard rock)	102	24	26	2.81	40	5.0	7.0	For these slopes poles will be used for measurement of movement by total station. Other details can be found in recommendations

Places	Cohesion kPa	Angle of internal friction	Bulk density kN/m^3	Average FOS	Saturation condition (%)	Height of bench, meter	Width of bench, meter	Comments
Mine coal bench(hard)	35	15.3	13.6	1.83	20	10.0	12.0	The bench width will be always more than the bench height, preferably by 2.0m. For these slopes poles will be used for measurement of movement by total station
BC Soil benches/ fragmented benches	39	28	19	2.06	40	3.0	9.0	For these slopes poles will be used for measurement of movement by total station. Other details can be found in recommendations

10.1.1 Mine coal bench

Since the thickness of the coal seam is 10.21m, therefore the total height of the coal seam can be worked by single lift with surface miner and without leaving any bench. The width of the bench must not be less than 12m. However, in places where the coal seam height is more than 10.21m a different consideration of benching with the approval of regulating agencies, is to be adopted.

The coal strength of the benches in the mine is between 60 to100 kg/cm^2 (6-10 MPa). At this strength the coal bench is supposed to remain standing and stable. But precautions of safety have to be maintained as per the observations on day to day basis. Any signs of local weakening of strength and excessive vertical and lateral load accumulation will be dealt with responses like removing man and property.

In order to reduce the scope of spontaneous combustion the cut coal cannot be kept stored on the bench and have to be evacuated within 5-6 hours of cutting the coal. In addition, the provisions for dousing the coal fire must be kept for use immediately upon a fire.

The coal benches can suffer from weaknesses of joints, faults and folds, etc. Different igneous intrusions of sills and dykes can also weaken the coal seam. As a result, in some parts of the rather solid coal seam there can be occurrences of burnt soil, coal and rocks which may have flow-able property leading to slope failure. In addition, such parts or locations can have old fire and also can catch fire as soon as they are exposed.

It will be the responsibility of the management of the mine to identify such occurrences and to caution the working personnel and manager of the property to take required safety measures. In cases of repeated occurrences of such geological problems (e.g. 5 such occurrences in 1 km of the bench length), the mine management will inform the appropriate regulatory authority to review the condition of working and if need be the bench height and other operating conditions can be again reviewed. Under regular operating conditions the points enumerated in sections 9 and 12 of this report must be watched, assessed, and precautionary steps to avoid unsafe conditions for men and property to be avoided.

10.1.2 Height and width of mine working OB benches

1. Height and width ratio of the BC soil slope will remain 1:3 (3m height and 9m width) up to total 7.00m thickness of BC soil.
2. Height and width ratio of benches (other than BC soil benches) slope will remain 1:1 (5m height and 5m width). Same pattern will be followed in the coal benches.

In the intact mine bench, rainfall led saturation of the overburden material, though continuously reduces the factor of safety, does not decrease beyond the acceptable limit. However, formation of cracks, presence of loose soil like material can substantially reduce the factor of safety. During the rainfall seasons of June to September, particularly the slope stability team would ensure that if the overburden shows signs of slope failures as given in sections 9 and 12 of this report, it must propose appropriate actions to the mine management, to save men and property.

10.2 Ultimate pit slope of the mine

In the top benches, up to the width of BC soil, up to 7.0 m, the OB bench height and bench width will be 3.0 m and 9.0 m, respectively. After 7.0 m the OB bench height and bench width will be 5.0 m and 7.0 m, respectively. The coal bench height and width shall be always 10.0 m and 12.0 m, respectively.

The ultimate pit will look like as in Fig.14.

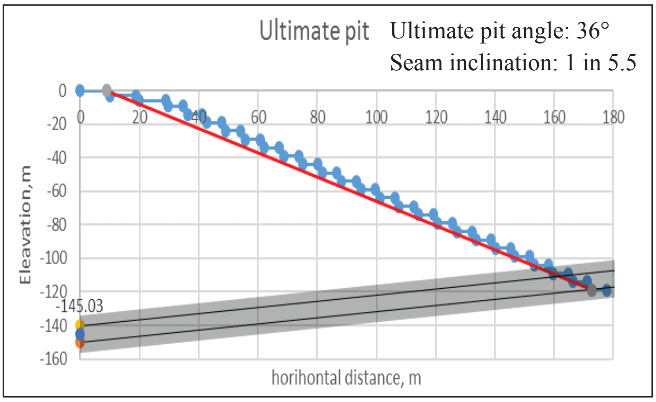

Fig.14: Ultimate pit of the mine

10.2.1 Height and width of OB rock dumps

Height and width ratio of the other bench dumps (other than BC soil dump) will remain 1:1.25 (20m height and 25m width) till the height of the other benches reach 60m. After 60 m, for further dumping up to maximum 90m, height and width ratio of 1:2 (10m height and 20m width) will be followed. In all such times available dump area for vegetation will be as far as possible vegetated with all season large tree green plantation, interspersed with patches of grass lands.

10.2.2 Height and width of BC soil dumps

Height and width ratio of the BC soil dump will remain 1:1.5 (10m height and 15m width) till the height of BC soil dump reaches 30m. After 30m, for further dumping up to maximum 45m, height and width ratio of 1:2 (10m height and 20m width) will be followed. In all such times available dump area for vegetation will be as far as possible vegetated with all season large tree green plantation, interspersed with patches of grass lands.

In the dumps, rainfall led saturation of the overburden material, continuously reducing the factor of safety, might decrease beyond the acceptable limit. However, formation of cracks, presence of loose soil like material can substantially reduce the factor of safety. During the rainfall seasons of June to September, particularly the slope stability team would ensure that if the dumps show signs of slope failures as given in Sections 9 and 12 of this report, it must propose appropriate actions to the mine management, to save men and property.

10.2.3 Internal dumping

Internal dumping can be done as soon as sufficient space is made available in the mine. Internal dumping can be done, keeping the toe of the dump at least 100m away from the active working or the maximum height of the working, whichever is more. Internal dumping shall be started from bottom upwards so that the dumped material is made compact. Before starting the internal dumping, the floor should be blasted by drilling 2 to 3m holes or made level by ripping, if needed, so as to increase the surface friction. Internal dumping should not be done on the slippery wet or water accumulated floor. Height and width ratio of the bench dumps will remain 1:1.5 (20m height and 30m width) till the height of all the benches together reach 60m. It is recommended that each of the slope length for the OB dump should be 33.25m with a minimum of 30.0m terrace before another slope. After 60m for further dumping up to 90m height and width ratio of 1:1.5 (10m height and 15m width) will be followed. Here, it is recommended that each of the slope length for the OB dump should be 16.25m with a minimum of 15.0m terrace before another slope. Above 90m for further dumping there should be a scientific study to assess the performance of the method till 90m and to suggest the appropriate method post 90m.

It is advised to construct a protective barrier at the edge of the bottom of the internal dump, not less than the height of 2m.

In all such times available dump area for vegetation will be as far as possible vegetated with all season large tree green plantation, interspersed with patches of grass lands.

10.3 Monitoring of loose OB and BC soil slope

It is recommended that long poles/pegs with cement blocks at the bottom are to be left during of the preparation of slope. The interval between the poles/pegs should be in grid of 100m × 100m (in staggering pattern). The position of the pole/peg will be measured from a reference point to observe any displacement by total station method of surveying. The objective of such assessment is to observe whether there is any abrupt disturbance on the slope during normal working period. For all black cotton soil dump slopes the top of the poles/pegs will be monitored for displacement once in every 30 days during dry period of October to May. For all other waste slopes also the monitoring will be done once in every month. During the times of heavy rainfall, normally between the months of June to October the pole/peg displacements should be monitored once in every 7 days in all waste slopes. In the case of excess rainfall under extraordinary conditions the monitoring should be done twice in every week, with approval of the mine manager.

Once the waste dumps, particularly the black cotton soil dumps are vegetated with all season green plants of at least 2.0 m height the frequency of total station survey of the slopes can be done once in 3 months. Extra precaution requiring more frequent total station surveying during rainy season should be taken in consultation with mine manager.

10.4 Monitoring of bench slope

It is recommended that long poles/pegs with cement blocks/iron pegs at the bottom are to be left during the preparation of bench. The interval between the poles/pegs should be in grid of 100m × 100m (in staggering pattern). At least 2m of the poles/pegs should be below ground and 2.0 m above ground. The poles /pegs should be of such construction that they remain intact for at least 5 years in position. The position of the pole/peg will be measured from a reference point to observe any displacement by total station method of surveying. The objective of such assessment is to observe whether there is any abrupt disturbance on the bench during normal working period. For all black cotton soil benches, the top of the poles/pegs will be monitored for displacement once in every 30 days during dry period of October to May. For all other benches also the monitoring will be done once in every month. During the times of heavy rainfall, normally between the months of June to October the pole/peg displacements should be monitored once in every 7 days in all benches. In the case of excess rainfall under extraordinary conditions the monitoring should be done twice in every week, with approval of the mine manager.

11.0 Slope stability engineering

11.1 Terracing of the slope of broken materials

All slopes, more particularly the loose slopes, must be treated with terracing and diversion ditches. The slopes and terraces will be preferably planted with all-weather local green varieties of trees with grasses in between.

Bench terraces are particularly suitable where marked seasonal variations exist in the availability of water. The approach consists of converting relatively steep land into a series of horizontal steps running across the slope. The width of the terraces is determined based on the soil depth, slope, amount and distribution of rainfall, and intended farming practices. In general, inward sloping terraces are constructed in areas of heavy rainfall and less permeable soils. The depth of cut and fill have to be balanced, thus the interval is equal to double the depth of cut. At the edge of the terrace there will be a berm. The berm will have 0.5m of height with a foundation of 1m below ground. A schematic diagram is attached as a guideline.

11.2 Slope/diversion ditches

The diversion/slope ditches can have different shapes: V-shaped, rectangular, trapezoidal, and half-circled. Experience demonstrates that material characteristics and construction method play a very important role in ensuring that the drainage system will last for many years. In the mine area the ditches will be normally made of boulders, rock and stone-all compacted. But to give the ditches a good life concrete filling at the top will be necessary.

In some cases, high quality reinforced concrete may be used for the drainage system. The characteristics of the concrete which is made to last are: high compressive strength, minimum characteristic strength f^{ck} is 20 MPa, low water-cement ratio less than about 0.5, high cement dosage, greater than 350 kg/m^3. The minimum concrete thickness is 150 mm and construction is to be carried out with cast in place concrete. Precast concrete has demonstrated that it is not as long lasting, as water tends to underflow ditches. Fig.16. shows an example of V-cross section channel geometry.

The sidewall collapse and filling of the ditches are common.

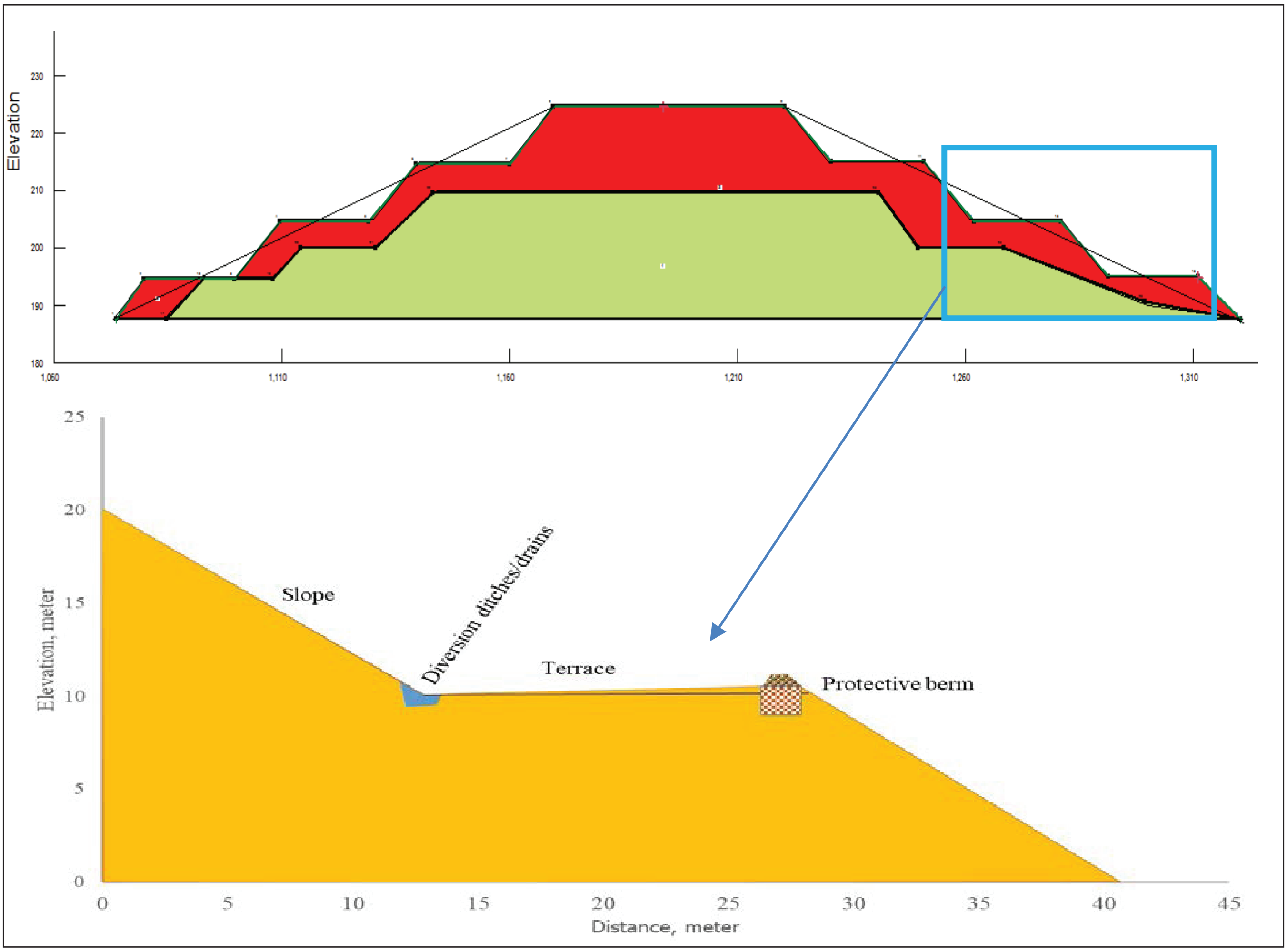

Fig.15: Formation of terracing of a dump

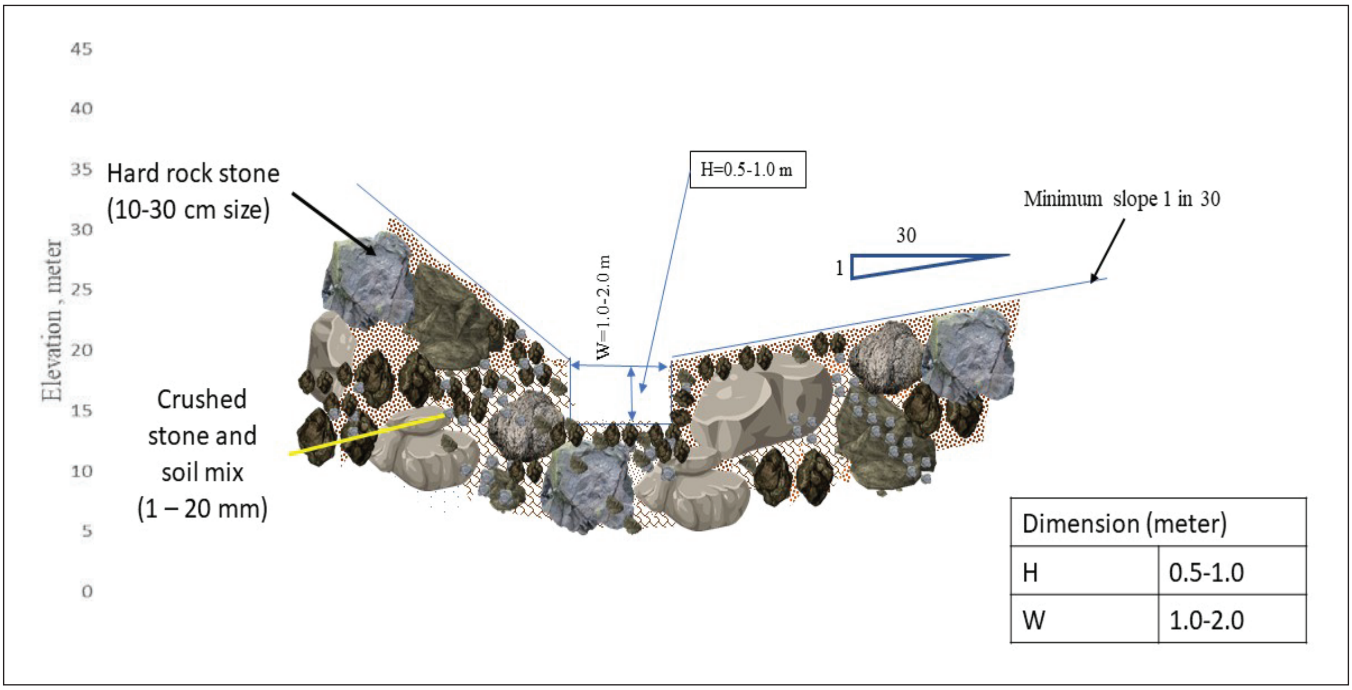

Fig.16: Design and construction of normal slope/diversion ditch in a mine

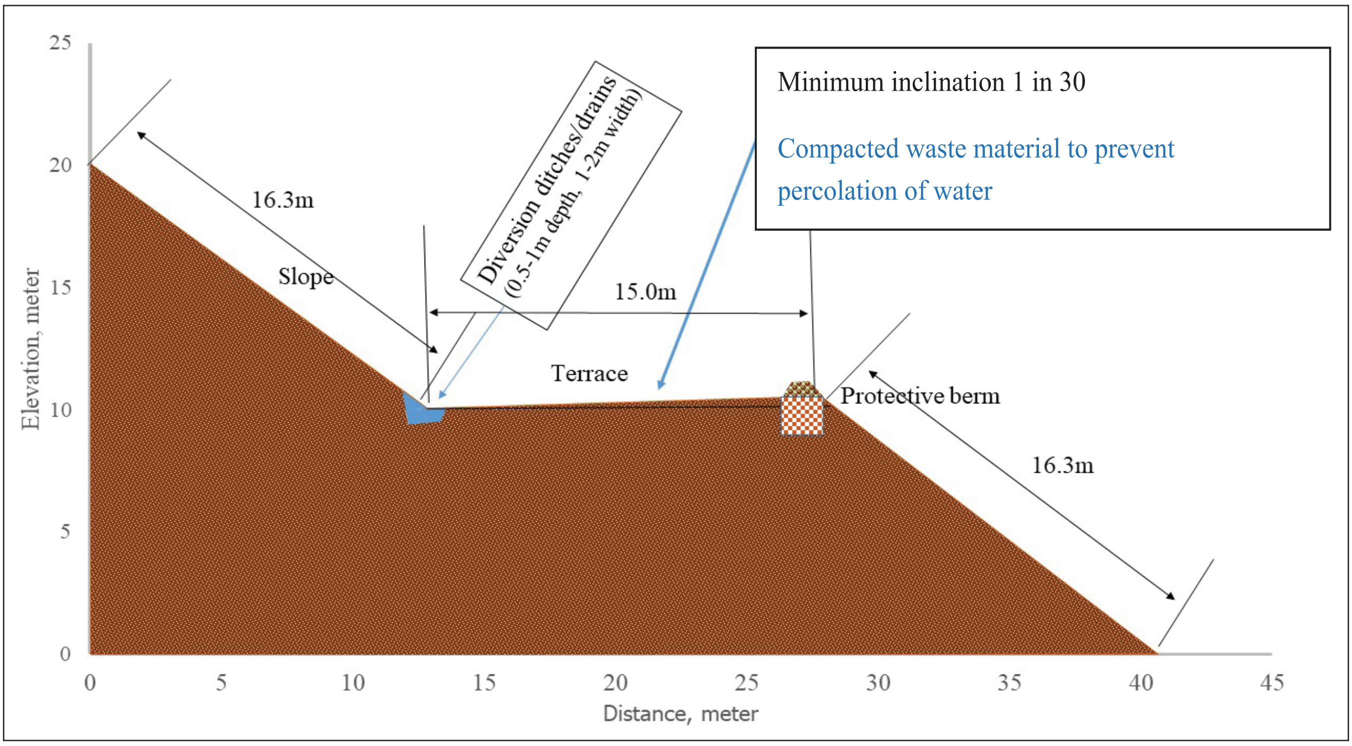

Fig.17: Terracing of top black cotton dump

The ditches and drains are to be cleaned at the end of every monsoon season of the boulder, dirt and sediment settled on them. This is crucial to their performance.

It is recommended that the slope length for the OB dump should be 32.5m with a minimum of 25.0m terrace before another slope. It is also recommended that the slope length for the BC soil dump should be of 16.3m with minimum of 15.0 m terrace before another slope.

It is also recommended that both OB and BC soil dump slopes and terraces are vegetated with large plant and grasses as per procedure mentioned below. Please see Figs. 23, 24 and 25 for more details.

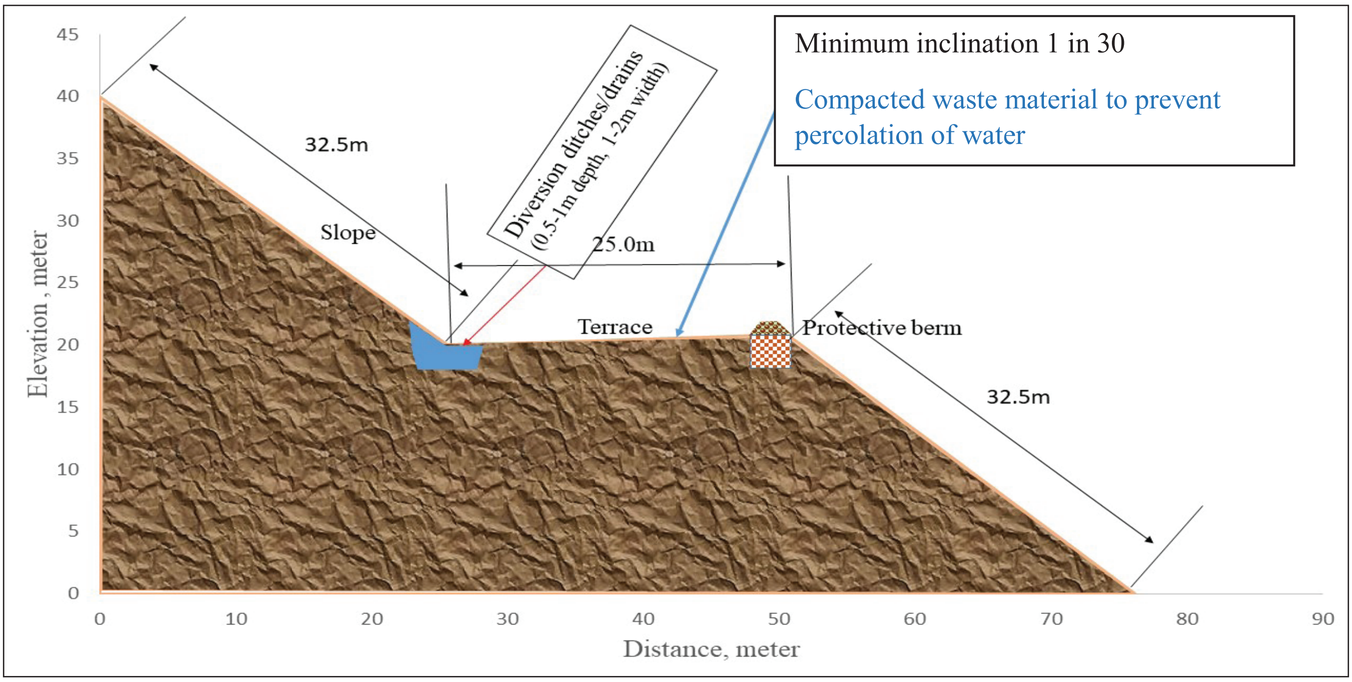

Fig.18: Terracing of overburden waste dump

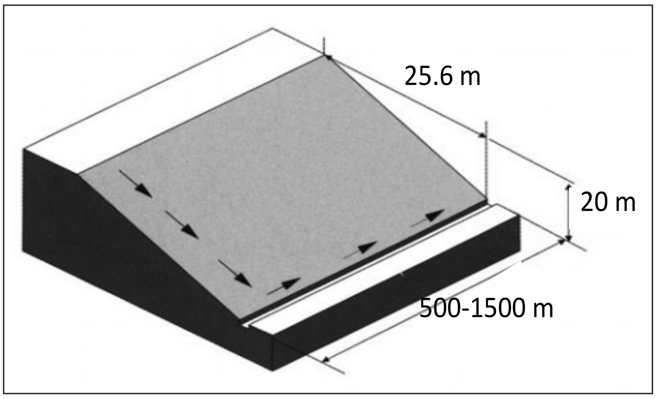

Fig.19: Suggestive slope drainage design (will be applied as per terracing – diversion ditch combination)

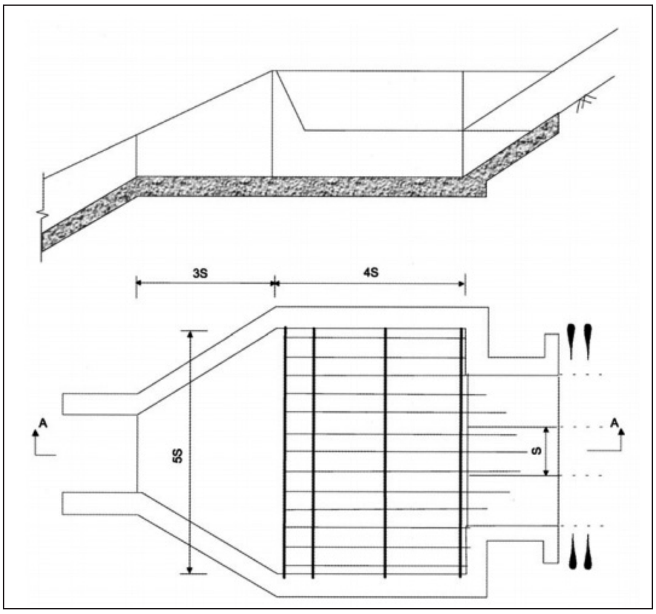

Fig.20: Catch pit with large particles trap

11.3 Catch pits

Catch pits are to be made at the end of every 3 slopes to reduce the impact of turbulence of speedily running water in the connected diversion ditches. Catch pits are used at junctions of channels with different slopes, to minimize the inevitable turbulence and splashing that occur at these points. At these junctions, the channels should be deepened with an added freeboard allowance to contain this turbulence. As a result, catch pits are vulnerable to blockage by debris, and therefore must be cleaned seasonally. Catch pits, usually made of reinforced concrete, can be opened or closed, but with removable lids to allow maintenance works. The catch pit cover can be built with concrete slabs or with metallic grids. This latter alternative is also recommended as a filter, which may prevent large particles obstructing the channel (Fig.20)

The catch pits are to be cleaned at the end of every monsoon season of the boulder, dirt and sediment settled on them. This is crucial to their performance.

11.4 Application of horizontal drains

In the initial years of loose material dump development, subsurface drainage is recommended. Subsurface drainage systems are simple and easily built. Most drains are made of 7.5cm to 10cm diameter PVC perforated pipes, wrapped in filter fabric, which are introduced in pre-drilled holes at gradients of about 10% uphill, as indicated in Fig.21. To avoid blockage of holes by vegetation, the first 1.5m of the outlet end of the perforated pipe should not be perforated.

If the slope profile consists of heterogeneous soil and/or fractured rocks, the length of the horizontal drains must traverse as many permeable materials as possible. A previous survey of the fracturing system and dip angle to enable a good understanding of the geological complexity is strongly recommended.

As a general rule, long drains with larger spacing are more efficient than short drains with less spacing. Moreover, the smaller the slope angle, the longer should be the drain. PVC pipe drains should not exceed 40m in length; for longer drains stiffer pipe materials (stainless or galvanized) are recommended. Horizontal drain life time depends on the chemical composition of the water, installation method and above all a subsequent maintenance programme. In the loose slopes of BC soil and broken overburden the pipes are to be placed in a spacing of 100 m in every two slopes. Between two row of drains, the positon of the pipes will be kept staggered. It is of primary importance to install regular field instrumentation to assess pressure head reading fluctuation, in order to adjust drains spacing to reach pore water pressures specified in the drainage design.

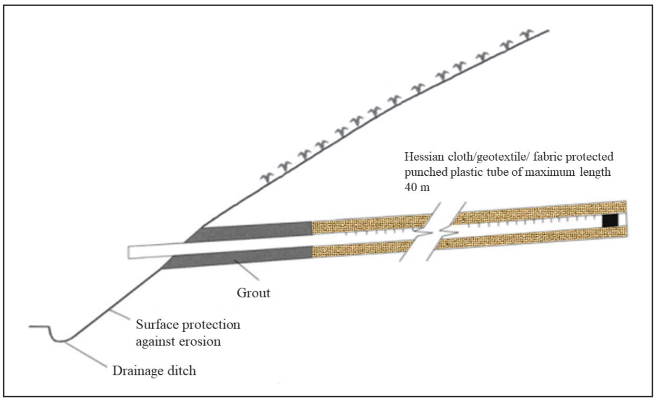

Fig.21: PVC perforated pipes, wrapped in filter fabric inserted in a dump slope.

The filling of the pipes and obstruction are common. The pipes are to be cleaned at the end of every monsoon season of the boulder, dirt and sediment settled on them. This is crucial to their performance.

11.5 Concrete slope drainage

In some cases, where heavy vehicles and HEMMs would play on the loose material slope bench for a considerable time (on a regular basis for more than 3 months), slope drainage should be concrete type. High quality reinforced concrete may be used for the drainage system. The characteristics of the concrete which is made to last are: high compressive strength, minimum characteristic strength f^{ck} is 20MPa, low water-cement ratio less than about 0.5, high cement dosage, greater than 350 kg/m^3. The minimum concrete thickness is 150 mm and construction is to be carried out with cast in place concrete. Fig.22a shows an example of U-cross section channel geometry with surface protection and some design guidelines. Fig.22b presents the rectangular cross-section. The design sequence starts with the cross section definition and channel gradient determination. It is always recommended to have a channel slope coincident with ground slope, to prevent additional earthworks. The next steps are the evaluation of the maximum discharge and the admissible flow velocities, respective to the different channel heights, and evaluation of the flow regime (Froude number). If channel design results in flow velocity higher than the admissible value, it is recommended to introduce energy dissipaters, as shown in Fig.20.

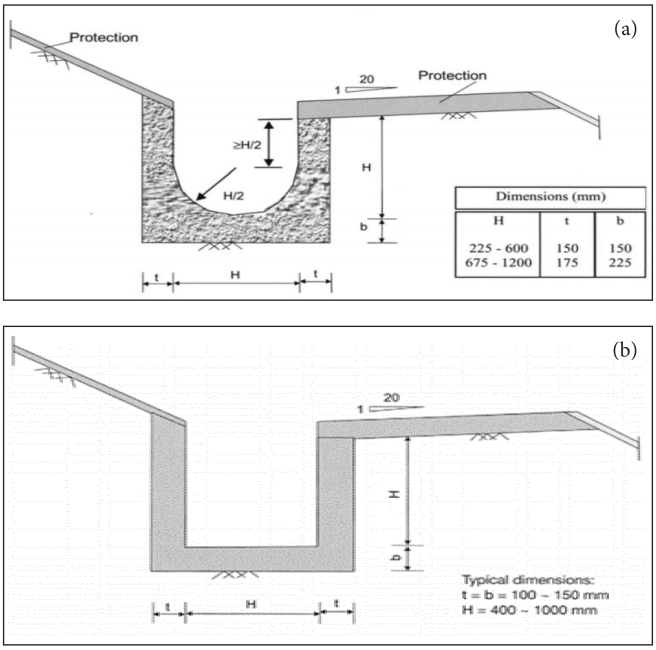

Fig.22: Concrete slope drainage structures: (a) U shaped concrete ditch, (b) Rectangular concrete ditch

11.6 Plantation

1. Spread fallen leaves/rice straw etc. on top of both BC soil dumps and OB dump waste dumps as well as on the terraces. Such material can be collected locally on a regular basis.
2. Plant seeds/saplings of local large trees in consultation with local forest personnel in a manner that the plants survive. In 1.0 m × 1.0 m spacing along columns and rows. Make sure that more than 50% of the plants survive and grow in each plantation cycle in each site of OB spoil dumps and BC soil dumps.
3. Between the plantations of trees spread common grass of the area in consultation with local forest personnel
4. Continue 1 to 3 steps for more than 4 years so that all the available dump surfaces are covered with tress and grasses.
5. Take necessary precautions so that the plantations, seeds and saplings are protected from herds, fire and cutting of trees.
6. Use bamboo and other green fencing methods but preferably not wire fencing.

The vegetation cover has positive effect on the cohesion of the dump soil in fact cohesion increase with increase in the area of vegetation and the root length of the plants. Thus FOS for OB dump slope will increase remarkably. For fully drained condition increases in FOS can be seen at different percentage of vegetation cover and root length of plants in Table 12. Figs. 23, 24 and 25 show how the plantation will look after 2-3 years of the dumping.

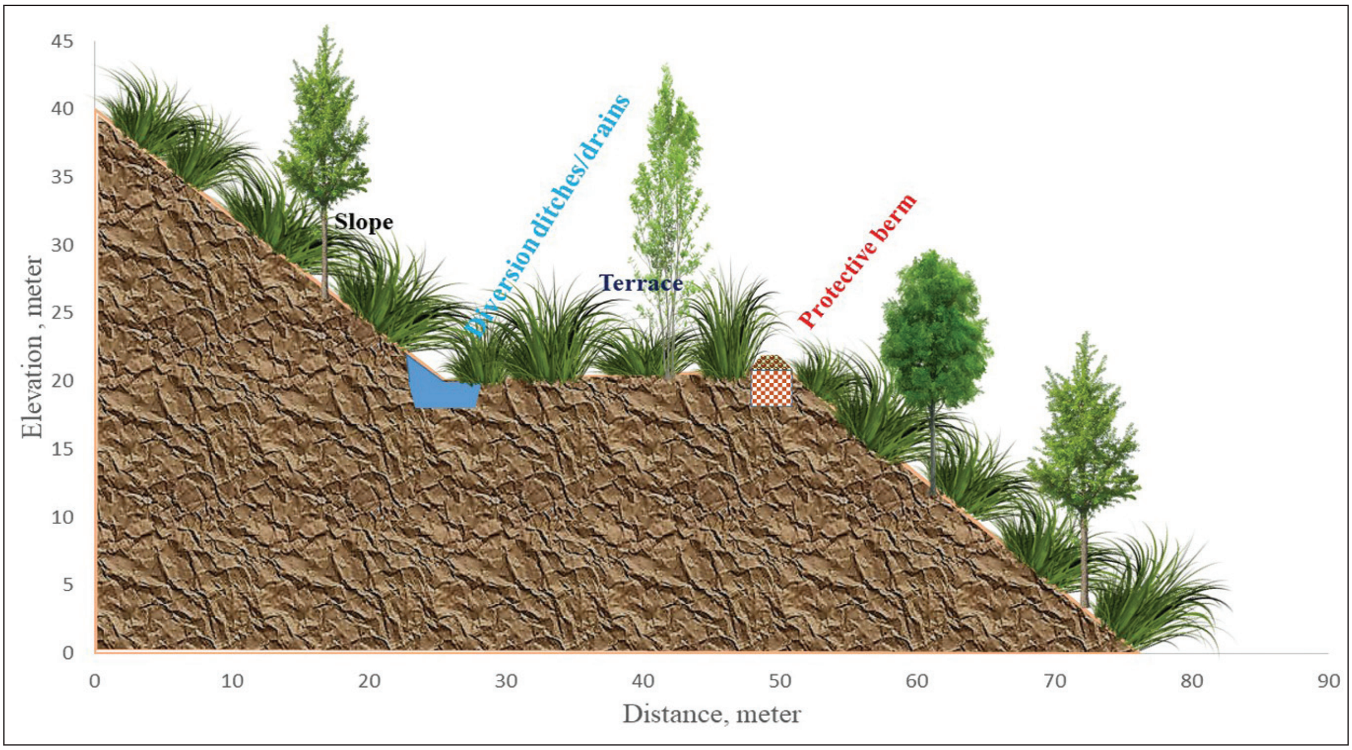

Fig.23: Plantation in the OB dump bench

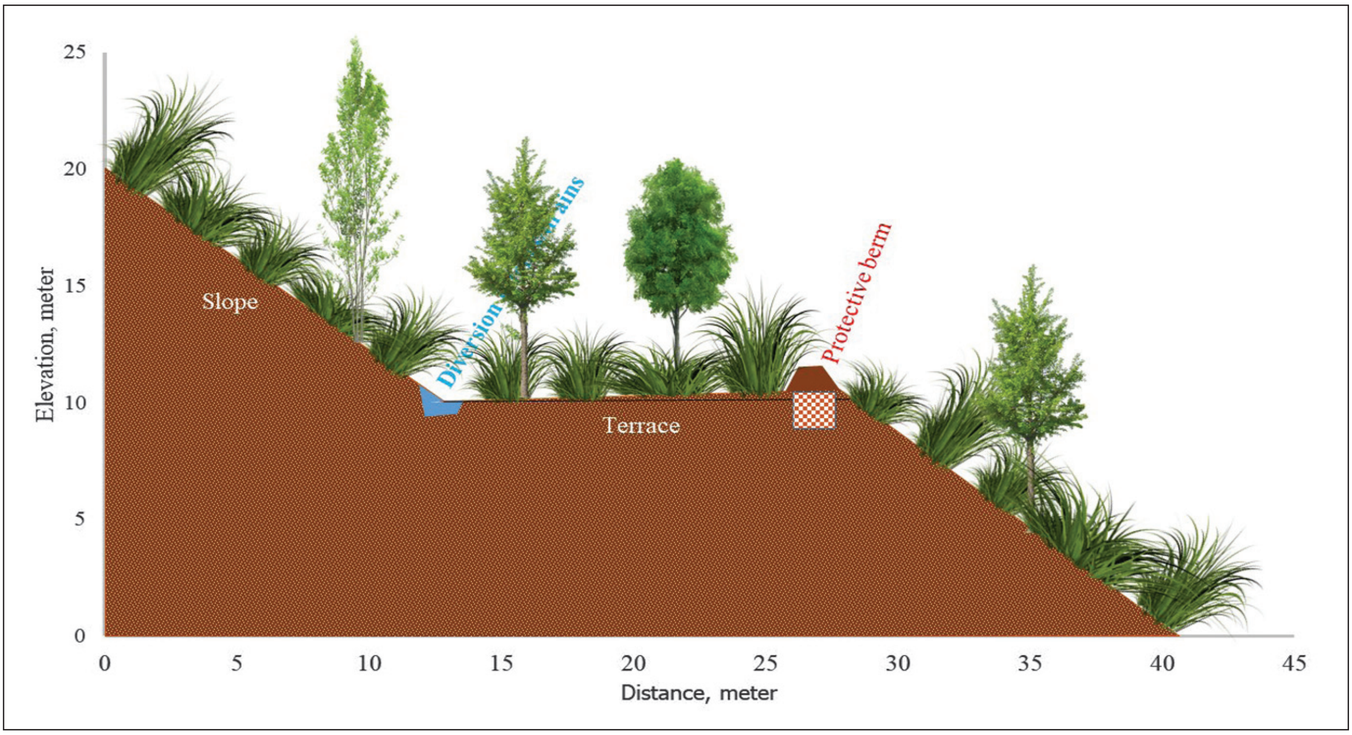

Fig.24: Plantation in the black cotton soil dump

Table 12: Effect of vegetation cover on factor of safety dump slope.

Vegetation covers	OB broken dump (hard rock)	BC dump soil
	FOS	
30% green cover with root length 5 cm cohesion increase 5%	1.02	1.17
30% green cover with root length 10 cm cohesion increase 10%	1.05	1.19
50% green cover with root length 10 cm cohesion increase 20%	1.08	1.26
50% green cover with root length 15 cm cohesion increase 30%	1.12	1.31
75% green cover with root length 10 cm cohesion increase 40%	1.19	1.38
75% green cover with root length 15 cm cohesion increase 50%	1.24	1.46
100% green cover with root length 15 cm cohesion increase 60%	1.28	1.48
100% green cover with root length 20 cm cohesion increase 70%	1.46	1.61

11.7 Drainage through interconnected ditches

Drainage ditches can be constructed with different shapes and sizes. The appropriate size and shape for a particular site depends upon such factors as the expected runoff, site condition, and availability of resources and construction materials. Usually a waterway can be triangular, trapezoidal, or parabolic. A parabolic shape is hydrologically more efficient and easier to construct. Usually, a gradient of less than 5% is preferred; in a normal course it should not exceed 10%.

The diversion drainage/ditches are to be connected to form garland drain that would lead to the sediment pond. The diversion ditches are liable to collapse due to slope movement and collection of particles on drain surface. These drains must be maintained regularly particularly before and during monsoon season, the water drainage through the drain must also be checked for capacity and flow of drainage.

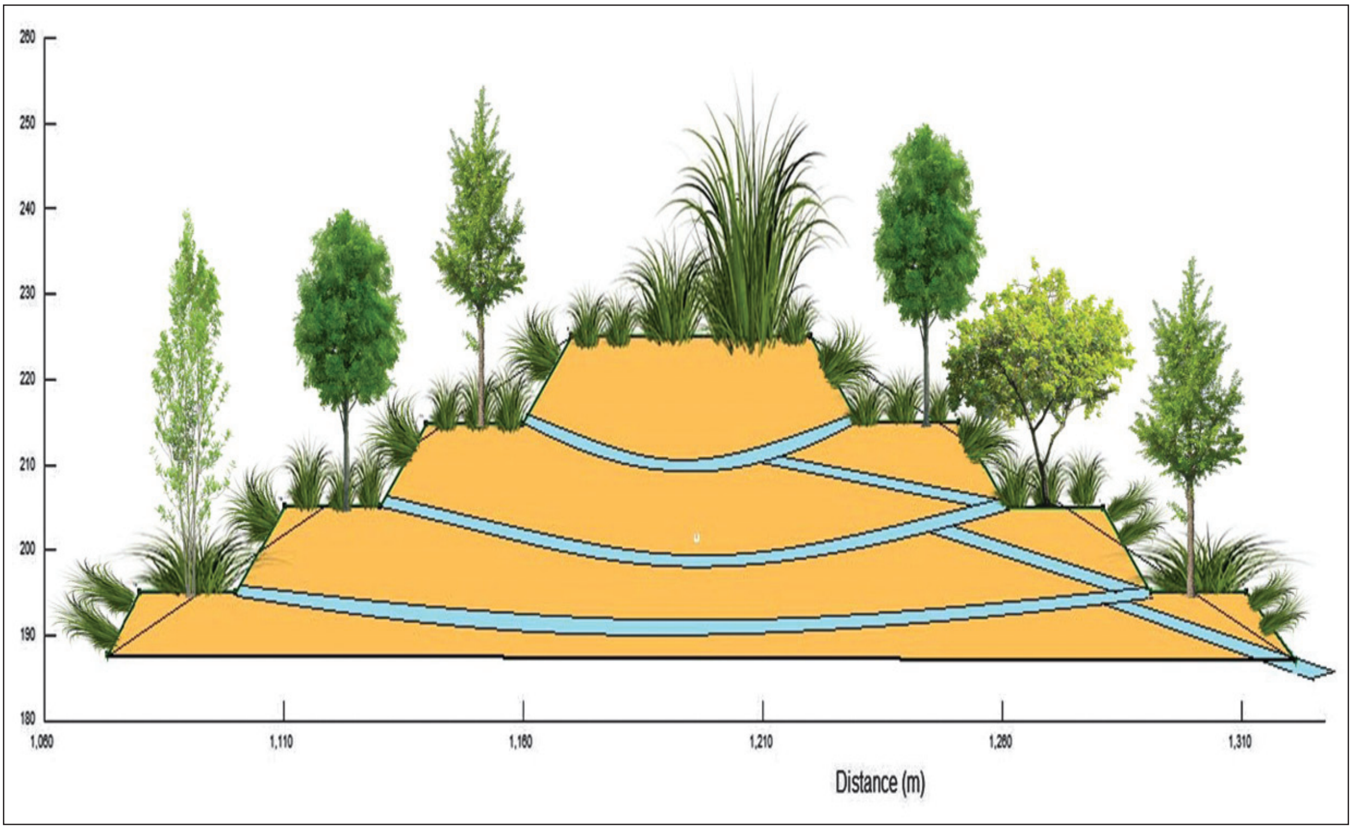

Fig.25: Drainage and plantation in the OB and BC soil dump. All the diversion ditches in the terraces have to be connected in a manner so that the water collected in the ditches, via drains now looking like a garland, finally go to the sediment pond outside the dump area.

12.0 Slope stability management on the basis of the CMR, 2017

1. Mine manager in consultation with the safety officer and other mine officials shall appoint a team of qualified persons including assistant managers and above, having at least 2nd class Mine Managers Certificate of Competency, and with one or two qualified civil engineers to periodically review the conditions of the mine slopes: ultimate and operating unbroken mine and overburden slopes and benches, broken overburden dump slopes and top soil benches and slopes.
2. The slope stability team must work in close liaison with the safety committee.
3. The period of review on dry months of October to May, should be once in 2 weeks whereby every slope will be assessed for safety inspection and assessment that will be properly recorded and signed, and shall remain with the office of the manager. The manager will be reported of the details every time in writing of whether the slope conditions have changed of late or changing rapidly.
4. The period of review for predominantly rainy and wet months of June to September the inspection shall be nominally carried out once every week. The manager will be reported of the details every time in writing of whether the slope conditions have changed of late or changing rapidly. The period between successive inspections by the team will change as per the demands of the situation.
5. The features of impending slope failure indications are:
   i. High water seepage from wide areas on the slope areas and from the toe.
   ii. Continuous rolling down of rock blocks from the top.
   iii. Excessive and increasing slurry flow from one place or from several places in the toe and face of the slope.
   iv. Increasing number of rill and gullies in short period of time of few hours,
   v. Visible swelling of soil, particularly black cotton soil, and separation from the layers, and
   vi. Visible cracks developed and extending in short period of times from one part to another.
6. The mine management must make a checklist of indications of slope failure or collapse that need to be looked into in situations where the slope un-stability can be out of control.
7. The history of slope failures in the Majri area point that most of the failures have taken place in the period of incessant rains or immediately after such rain episodes. Events of short period (up to 1 hour) heavy rainfalls and events of medium to heavy rainfalls for longer period (up to 24 hours or more) are to be particularly taken care of. The office of area safety officer shall heed to such forecasts, now reliably available on the net and media, and direct and participate with the team to make at least one inspection every 12 hours or less, as found necessary. In such events, all operational places should be considered for immediate clearing of workmen, property and asset. The team should document and report any such instances to the manager of the mine and if they are unanimous in voicing dangers of slope failure, the manager should take immediate action to save workmen and property and restrict work till all clearance reports are tabled.
8. Any alarm or alert raised by the team and the guidance by the team headed by the safety officer must be reported in writing to the manager to take actions, as may be found necessary, related to stoppage, and evacuation of people, equipment and other assets. In no occasions, the manager should either take or encourage unsafe acts or daredevilry to maintain production at the cost of workmen and property.
9. The team should also listen to the mine workers on the sites, and should engage discussions to look for features that can be considered dangerous and that need appropriate actions.
10. All such actions must have to be reported appropriately to DGMS as per the law prescribed.

13.0 Conclusions

A thorough study has been conducted on the slope stability of amalgamated Yekona mine of WCL, India. The study reports that for the slope stability both engineering and observation and inspection management will be the key. Quality of engineering in the slope stability control particularly during the rainy periods and occasional high rainfalls, and to be prepared of it, and management have been highlighted.

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