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Dump Slope Stability Analysis – A Case Study

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Abstract: In opencast mining operation, the stability of waste materials stands at high priority from the safety and economic perspective. Poor management of overburden (OB) dump results the instability of slope in an opencast mine. The present paper deals with the stability analysis of dump material of an opencast coal mine at Talcher coal field, Angul district, Odisha, by means of different geotechnical parameters and mineralogical composition affecting the dump slope. The prolonged rainfall in the mining area causes dump failure and loss of valuable life and property. A recent dump failure that occurred in 2013 at Basundhara mines of Mahanadi Coalfields Limited (MCL), Odisha, took 14 lives, and created problems for the mining industry. Most of the dump failure that occurs in the study area are mainly due to increase in pore water pressure as a result of rainfall infiltration. The stability of the waste dump was investigated using the limit equilibrium analysis to suggest an economical, sustainable and safe disposal of the dump in the study area.

Keywords: Dump stability, Talcher coalfield, Limit equilibrium methods, Odisha.

INTRODUCTION

In present days, the demands of coal has increased for industries as well as in domestic purposes. Recent year has seen a marked increase in the production of coal to meet the demands as mentioned by Coal India Limited (CIL, 2010) report, in the past years viz; 2011, 2012, 2013, 2014 were 431.32 Mt, 435.84 Mt, 452.211Mt, 462.442 Mt respectively. The share of the opencast mining is increasing day by day to ensure maximum resource recovery. The volume of overburden waste material has also increased in and around mining areas leading to dump slope vulnerability. Significant area of land are exploited during mining operations and also replace existing ecosystems with unwanted waste materials in the form of mine spoil dumps (Tripathi et al. 2012). Coal mine waste dumps require large amounts of land which can lead to pollution of both atmosphere and water (Adibee et al. 2013). Stability of overburden material is essential for smooth mining operations, hence proper management of dump is required in the mining lease area to avoid any slope failure. Improper management of dump is very hazardous for the mining activities (Richards et al. 1981; Vishal et al. 2010; Kainthola et al. 2011; Pradhan et al. 2011; Gupte et al., 2013; Poulsen et al. 2014). There are a number of cases where dump failure have been encountered in India which has caused significant damage to mining properties, loss of lives and interruption in production (Bowman and Gilchrist, 1978; Speck et al. 1993; Kasmer et al. 2006; Singh et al. 2007; Sharma et al. 2011; Pradhan et al. 2014; Singh et al. 2014). Some of dump failures have occurred in Singareni colliery during December 2009 (Poulsen et al. 2014), Western Coalfield Limited, Nagpur, India (Kainthola et al. 2011), and one of the most recent dump failure occurred at Basundhara mines of MCL 2013, Odisha. Consequently, a proper design of internal waste dump should be done in order to preserve the safety of men and machineries (Fernando and Nag 2003; Hancock and Turley 2006; Sharma et al. 2011). In particular, abandoned waste dumps that do not receive proper repair and maintenance can often experience partial losses of slope and surface erosion (Blight et al. 2004; Cho et al. 2014). The presence of structural features influences the stability as well as surrounding environment of open cast mines (Arikan et al. 2010; Verma et al. 2013). Rainfall infiltration affects pore-water pressure distribution within the slope and also reduces the frictional strength of the slope material (Verma et al. 2013). The decrease in shear strength may initiate movement in dump slope along weak plane. The migration of rain water may enhance the discharge, leading to the development of tension cracks at various places of the dump slopes. Tension cracks are also generated due to shocks and ground vibration caused by poor blasting (Verma et al. 2013). The production of the Bhubaneswari mines has increased from last five year (Fig.4) which needs a proper and sustainable methods to dispose waste materials. Dump volume increase has an invariable relation with depth of surface mines and stripping ratio. This needs a thorough study to make mining sustainable and safe. The aim of this study is to estimate the stability and risk assessment of dump slope at Bhubaneswari open cast mine using limit equilibrium analysis.

GEOLOGICAL SETTING

The Talcher coal field is situated in the Angul district of Odisha near to Brahmani river and north of the Mahanadi river (Fig. 1). The investigated area is located in northern part of Talcher basin and confined by Latitudes 20°57'59"-20°58'43" N and Longitudes 85°09'10"-85°11'37" E. It is covered in toposheet no.73 H/1 of the Survey of India.The area is around 160 km from the state capital Bhubaneswar and at an average height of 139 meters above the mean sea level. The field area investigated is Bhubaneswari mines of Jagannath Open Cast Project (OCP) area which is 6 km from the Talcher town. Bhubaneswari open cast mine is bounded by Ananta and Lingaraj mines. The geological framework of lower Gondwana rocks in Talcher area is a continuous succession of strata representing a part of Damuda Group, which is divisible into the Karharbari, Barakar and Barren Measures formations from bottom to top which are most important coal bearing horizons of India (Fig. 2). Talcher and Karaharbari successions have an unconformable contact (Bhattacharya et al. 2005). The main rock types found in the area are diamictic, fine to medium grained sandstone, shale, medium to coarse grained sandstone, sandy shale and turbidites (GSI, 1997). Occurrence of coal seams has been established along the western fringe and northern boundary of Talcher coalfield (Manjrekar et al. 2006).

FIELD OBSERVATIONS

The detailed field investigation has been carried out at Bhubaneswari open cast mines to collect the representative samples and slope geometry for geo-technical tests which later used for numerical simulation (Fig.3). Bhubanes-wari OCP has both internal dump as well as external dump. Maximum height of the internal dump is about 70 meters and external dump is 50 meters. The average slope angle of different dumping site varies from 35° to 41°. Most of the dump material consist mainly of friable rock material with varied lithology and mineralogical composition. The major rock types of the dump materials are sandstone, shale and carbonaceous shale. The major soil type which comprise the dump are sandy soil and loose lateritic soil. The dump base is extremely weathered (Fig.5b) and face has been highly affected by rain water which has created gully erosion on the dump surfaces (Figs. 5a). Tension cracks are also identified on top of the dump slope which ndicate the initiations of failure of the dump masses (Fig.5c). Tension cracks are developed within the crown portion of internal dumps (Figs. 5c and 5d) and its width varies from 0.5 to 1.0 m. Development of tension cracks indicate the vulnerability of dump failure influenced by external forces (ground vibration during blasting, heavy earth moving machine etc). The internal dumps are very close to the coal exploration area and any failure of dump masses

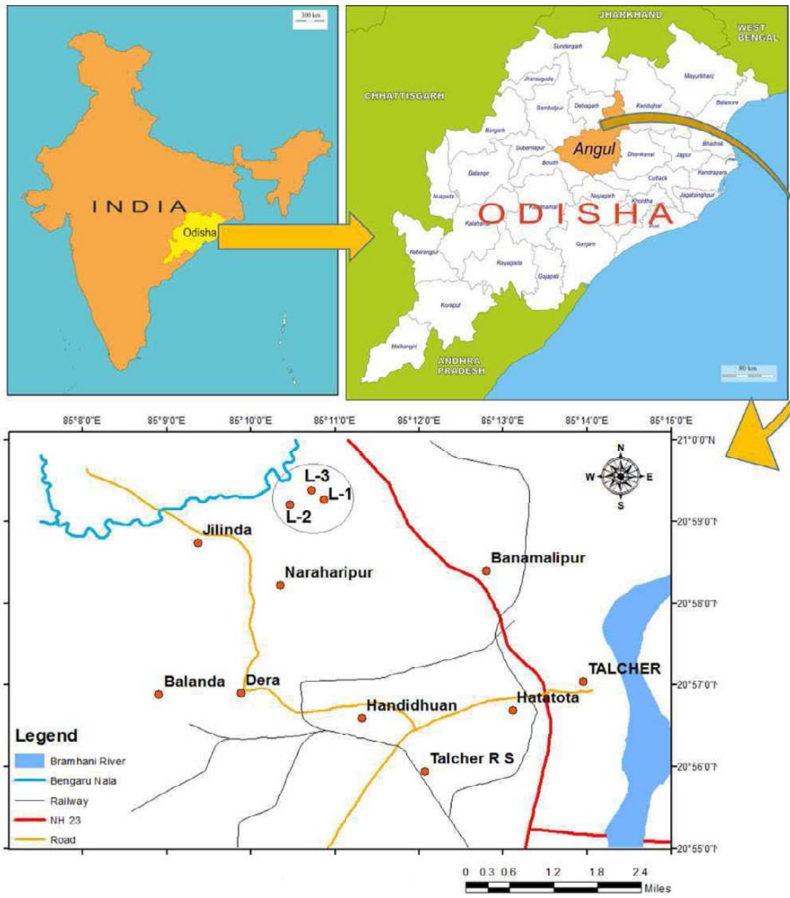

Fig.1. Location map of study area.

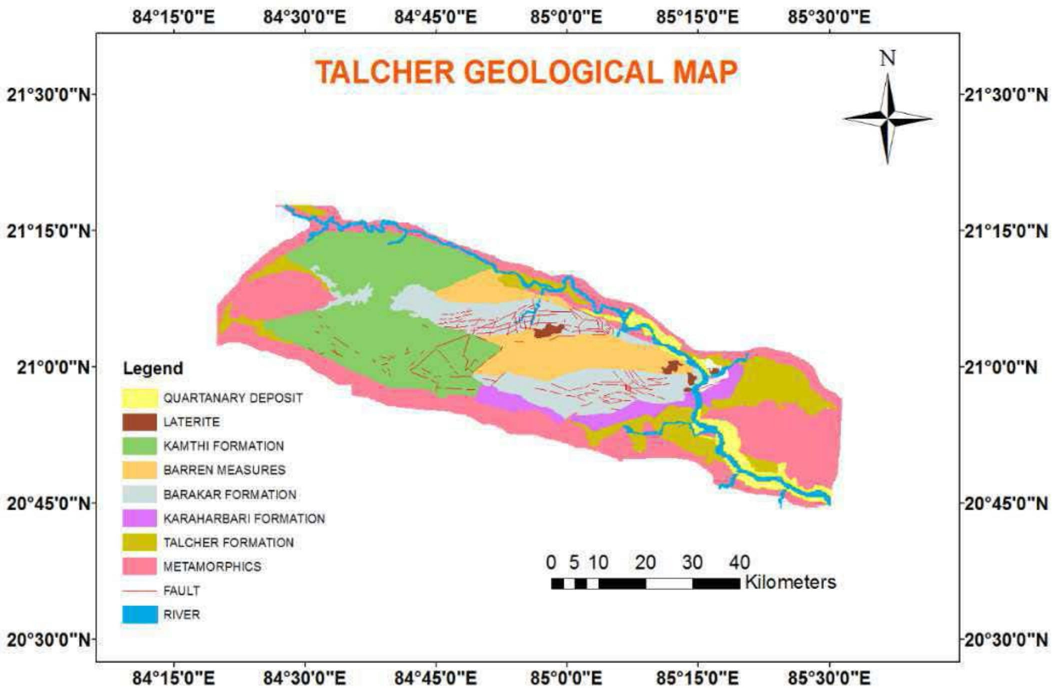

Fig.2. Geological map of Talcher area (Source GSI ,1997)

may cause extensive damage to lives and mine properties. Representative samples were collected from different strategic locations of the dump slope to determine the geo-mechanical characteristics of soil and rock units.

RESULTS AND DISCUSSION

Geological and Geomechanical Investigation

Many uncertainties exist in understanding the slope failure of waste dumps, because of their heterogeneity and complex pathways of fluid migration. A complete geological and geomechanical analysis of the dump materials provides useful information for better and safer designs of the dump slope. The mineralogical composition and internal structure of slope forming material were determined using XRD analysis and scanning electron microscope (SEM). Results show sandstone containing quartz, muscovite whereas shale sample contain small quantity of quartz, with chlorite and kaolinite are dominant. Soil samples analysis reveals that major minerals are quartz, magnetite, and potassium magnesium silicate (Fig.6-9). The presence of clay minerals result in the rapid decrease in cohesion during rainfall, as

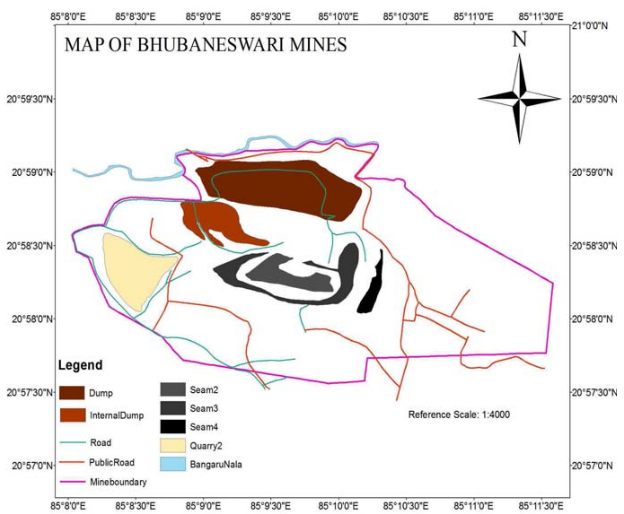

Fig.3. Outline of the Bhubaneswari OCP.

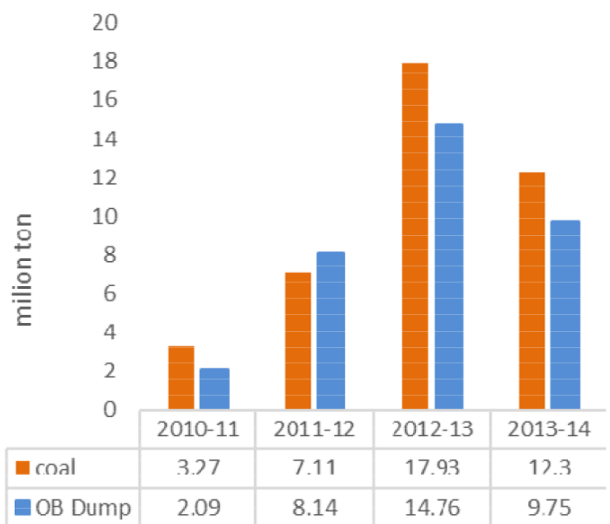

Fig.4. Production of Coal and OB at BOCP.

Fig.5. Field photographs showing: **(a)** Gully erosion, **(b)** Weathered top soil, **(c)** Failed dump slope, **(d)** Tension cracks.

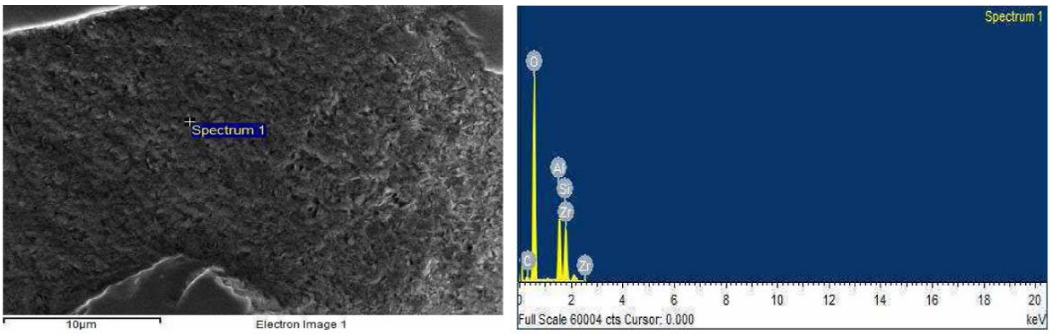

Fig.6. SEM photomicrograph of sandstone

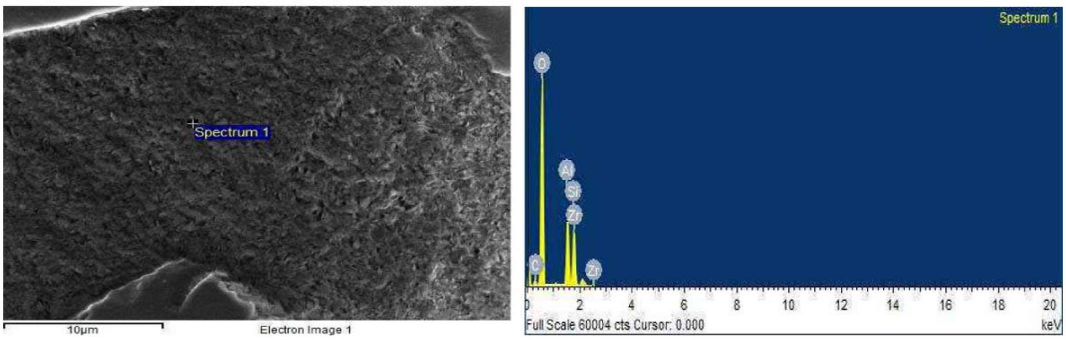

Fig.7. SEM photomicrograph of Shale

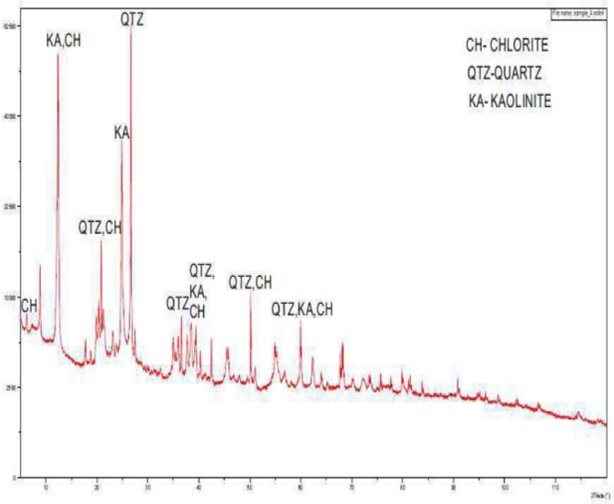

Fig.8. XRD analysis of Shale Sample

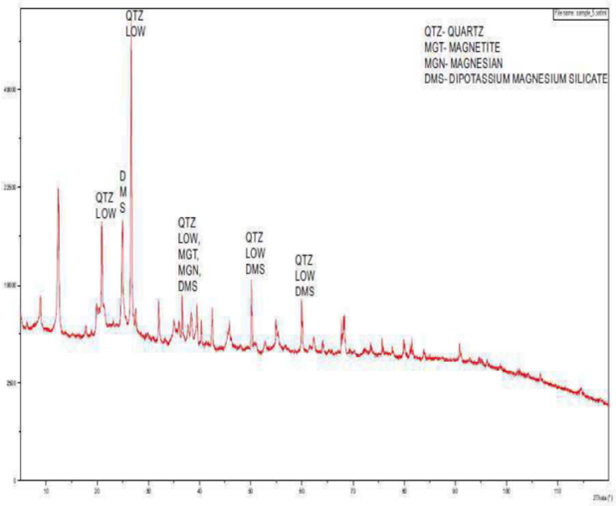

Fig.9. XRD analysis of soil Sample

loss of surface frictional contact between the grains due to high absorption of water. The SEM/EDEX analysis shows the surface morphology and elemental composition of the sandstone and shale. The presence of high percentage of oxygen intensify the chemical weathering process accompanied with rain water which significantly reduce the shear strength of the materials of a dump.

The grain size analysis of soil shows that the dominant fraction is silt 41%, followed by sand 37 % and gravel 19 % with 3% of clay size particles. The soil are sandy silt having minor amount of clay minerals. The presence of clay minerals give more plasticity to the soil which is one of the most important cause of slope failure. The different geomechanical properties of soil (Table 1) has been determined and plasticity index of most of the soils are low to medium. Plasticity chart (Fig.10) shows that four soil samples fall in the CL group i.e. inorganic gravely, sand-silty soil of low to medium plasticity and one sample falls in ML-OL group viz. organic soil of medium plasticity implying the soils are of low to medium density and moderate to high porosity. Low values of liquid limit, plastic limit and medium permeability indicate that the soil is moderately consistent. The permeability coefficient (K) determined by falling head permeability test ranges between 6.47×10^{-3} - 7.91×10^{-3}cm/sec. The low to moderate value of permeability causes significant pore pressure build-up within the dump masses due to ingress of water during rainfall which reduce the strength of materials during prolonged rain resulting in dump failure. The moderate porosity permits the rain water to percolate into the sediments which reduces the frictional resistance among the particles by decreasing the cohesion force.

The geomechanical strength parameters like uniaxial compressive strength (UCS), tensile strength, cohesion, angle of internal friction and point load strength index has been determined as per ISRM (1981,1983) standard. Slake durability index (SDI) test for rock fragments of dump materials have also been carried out to know the abrasion under action of fluid (Table 2) and the rocks in study area have medium to high durability as per ISRM (1978) standard. The geomechanical properties of soil has been calculated as per ASTM (2004) and ASTM (1998) standard.

FACTORS OF DUMP INSTABILITY

The number of factors which cause the dump failure are well explained by Singh et al. (1992); Singh et al. (1994); Singh et al. (2006); Kainthola et al. (2011); Singh et al. (2013). The factors which cause the failure are geometry, strength of dump material, hydrological and rain water condition of the dumping site, bearing strength of dumping ground and external load (Singh et al. 1992; Singh et al. 1994; Singh et al. 2006). The presence of structural disturbances like fault, joints and cracks are also responsible

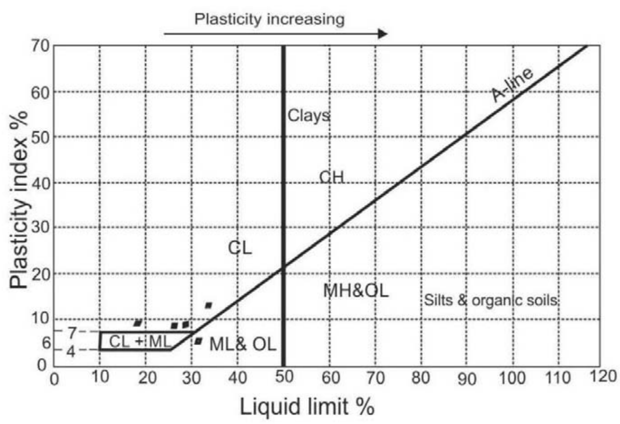

Fig.10. The Plasticity chart

Table 1. Plasticity Index and moisture content of soil

Sl. No	Liquid limit (%)	Plastic limit (%)	Plasticity Index (%)	Moisture content (%)
1.	19.0	10.0	9.0	20.48
2.	26.0	18.0	8.0	22.01
3.	29.0	20.0	9.0	21.62
4.	31.2	24.6	6.6	21.52
5.	33.0	20.55	12.45	36.38

Table 2. Geomechanical properties of rock

Sl. No.	Litho-type	UCS (MPa)	Tensile (MPa)	Point load (MPa)	SDI (%)
1.	Sandstone	19.75	2.23	1.39	64.18
2.	Sandy shale	38.36	1.96	1.64	71.06
3.	Shaly coal	11.00	0.60	0.50	91.20
4.	Coal	19.36	2.05	0.88	96.98

for dump failure. Groundwater flow condition plays a critical role on the stability of dump slope. Heavy monsoonal rainfall resulting raise in groundwater table is often believed to be the cause of dump slope instability (Yellishetty et al. 2010). Rainfall percolating through the weathered soil has triggered slope failures in circular shape due to loss of cohesion. The surface water flow also affect the dump stability as it increase the seepage force during prolonged rainfall. In Bhubaneswari OCP mines, gully erosion are due to surficial flow which play a significant role in dump face modification as well as inititate and migrate the tension cracks in the upper part of unconsolidated dumps. One of the most important triggering factor in situations of heavy to moderate rainfall is infiltration of water into slope forming material which consequently increases the pore pressure within the sediment and ultimately reduces the factor of safety of the slope forming material and possibly causing failure. The average rainfall in Talcher area is nearly 700mm which affect the different slope inside the mining area (Fig. 11). In the year 2014, the maximum rainfall precipitated in July and resulted in the major slope failure in the area under investigation.

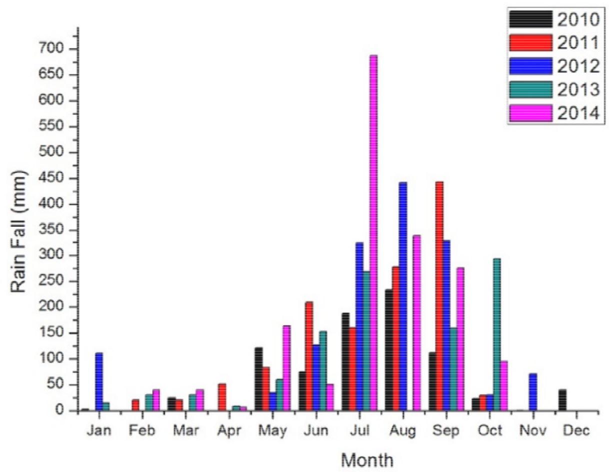

Fig.11. Rainfall variation in Talcher area. (Source: http://www.odisha.gov.in/disaster/src/RAINFALL/RAINFALL1/RAINFALL.html)

NUMERICAL ANALYSIS OF THE DUMP SLOPE

To understand the stability of dump slopes, analysis has been carried by using limit equilibrium method (LEM). LEM is the most common approach in the field of slope stability analysis (Cheng et al. 2014) and familiar numerical method for stability estimation of natural and engineering slopes (Poulsen et al. 2014). This method is based on the technique of slices in which the slope is divided into number of slices and factor of safety (FoS) is analysed by force and moment equilibrium for each slice and later by summation of all slices to finally produce the FoS. There are many LEM developed for slope stability analysis which includes Bishops (1955), Janbu (1954), Morgenstern-Price (1965), Spencer (1967) and Generalised Limit Equilibrium (GLE) method. Among these methods Bishop simplified method, Janbu method, GLE and Morgenstern-Price method are popular because factor of safety value can be quickly calculated for most of the slip surfaces (Abramson et al. 2002).

Bishop's simplified method (BSM) is commonly used for circular slip surfaces and Janbu's simplified method is commonly used for both circular and non-circular failure surfaces with the FoS determined by horizontal force equilibrium (Poulsen et al. 2014).

Bishop Method,

$$N' = \frac{1}{m_\alpha} / \Sigma\left(W - \frac{c' l \sin\alpha}{F} - ul\cos\alpha \right)$$

where $m_\alpha = \cos\alpha\,(1 + \tan\alpha\tan\phi'/F)$

Janbu Method,

$$F_f = \frac{\left[\Sigma\left(c' l + (N - ul)\tan\phi'\right)\sec\alpha\right]}{\left[\Sigma w\tan\alpha + \Sigma\Delta E\right]}$$

where $\Sigma\Delta E = E_2 - E_1$ = net interslice normal force. N' = Effective force acting on base. W = Weight of the slice. c' = Cohesion. ϕ' = Base friction angle. l = Base length. α = Base inclination angle of slice. F = Factor of Safety (FoS). u = Pore pressure. F_f = FoS. N = Normal force.

Models have been constructed for stability analysis of dump slopes using SLIDE software (2003). The results of LEM were obtained for three different location of Bhubaneswari open cast mine. All the LEM analysis has been carried out under saturated condition. Different input parameters of dump material are given in Table 3.

Dump location 1: The internal dump slope has a height of 30 m and slope angle 36° (Fig. 12). The results obtained from numerical analysis are shown in Figs.13-16. The failure plane of the dump starts from depth of nearly 2.5 m below the tension crack. Presence of water inside the tension crack developed hydrostatic force which causes reduction of shear strength.The FoS obtained from Bishop, Ordinary, Janbu and GLE Method respectively are 1.408, 1.332, 1.285 and 1.402. The analysis indicates that the slope is critically stable. A simple disturbance can initiate the failure.

Dump location 2: The internal dump slope has a height of 35 m and slope angle 39° is analysed (Fig. 17). Results obtained from the limit equilibrium analysis are presented in Figs.18-21. The FoS obtained using Bishop, Ordinary, Janbu and GLE methods are 1.206, 1.152, 1.134, 1.203 respectively. Analysis exhibits that the slope is critically stable.

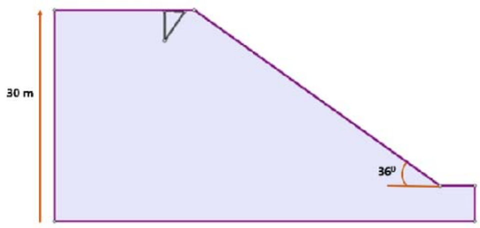

Fig. 12. Geometry of the model for Location 1

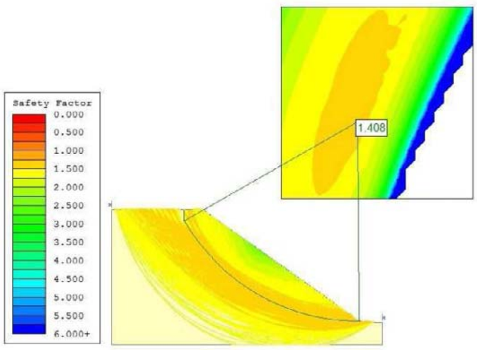

Fig. 13. Bishop Method

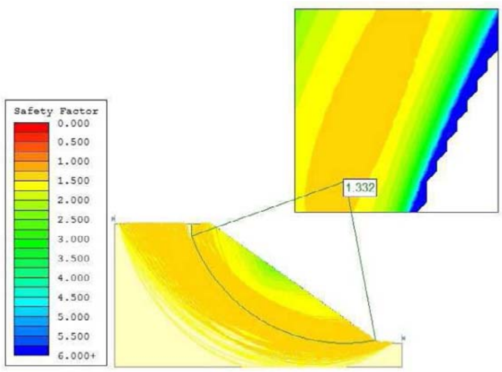

Fig.14. Ordinary Method

Table 3. Geomechanical properties used as input parameters

Geomechanical properties of dump material	Value
Unsaturated weight (kN/m^3)	18
Saturated weight(kN/m^3)	20
Cohesion(kN/m^2)	36
Angle of internal friction (degree)	22

Dump location 3: This is a part of external dump slope which has a height of 40 m and slope angle 41° (Fig. 22). Results are obtained from the limit equilibrium analysis and shown in Figs.23-26. The FoS of the dump slope in Bishop, Ordinary, Janbu and GLE methods are 1.107, 1.052, 1.037, 1.105 respectively. All these method shows FoS near to 1 which demonstrate that the slope is most critically stable.

In the present study, the analysis has been carried out at prevailling field conditions under gravity loading with constant height, base and slope angle. The mobilized shear stress of each slice along slip surface for both the methods (GLE and Bishop) has been plotted against slice no. (Fig 27). Since mobilized shear strength depend upon the effective normal stress acting on the failure surface, so the

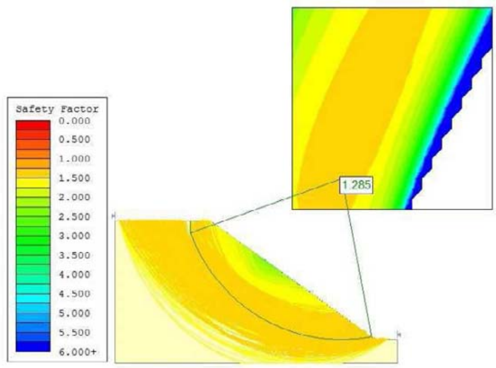

Fig.15. Janbu Method

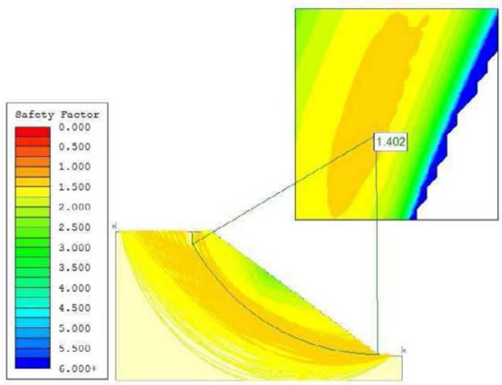

Fig.16. GLE Method

Fig. 17. Geometry of the model for Location 2

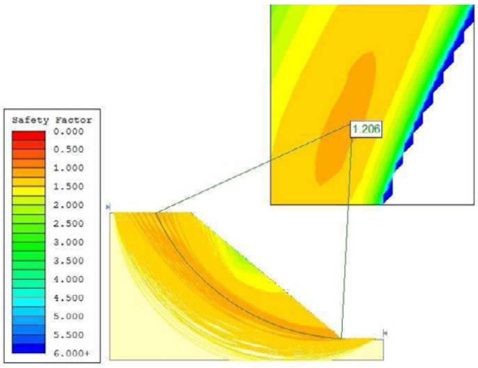

Fig.18. Bishop Method

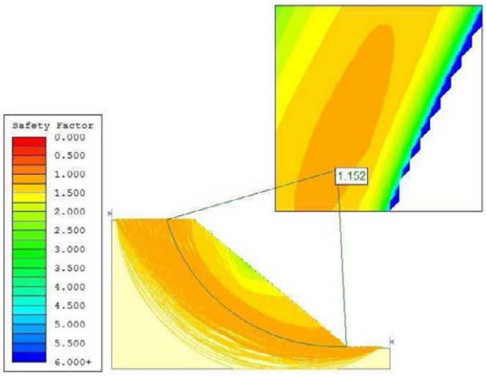

Fig.19. Ordinary Method

shear stress along the slip surface vary with the progressive failure. Here in both the LE method, dump 1 shows the highest shear stress values with smooth parabolic trend owing to large amount of overburden with loose material.

The limit equilibrium analysis has also been performed using Bishop and GLE method to correlate FoS against varying slope angle and slope height. The effect of slope angle variation on FoS has been plotted for both Bishop and GLE method (Figs 28). There is a common trend for both Bishop and GLE method in all the three dump slope which shows exponential decrese in factor of safety with increase in slope angles. For both the methods, dump 1 has more or less smooth curve with highest FoS 1.408 at slope angle 36° and lowest 0.97 at 58° and for dump 2, FoS is less affected with slope angle between 50° and 58°. Dump 3 posses the lowest value of FoS of all the three dumps against

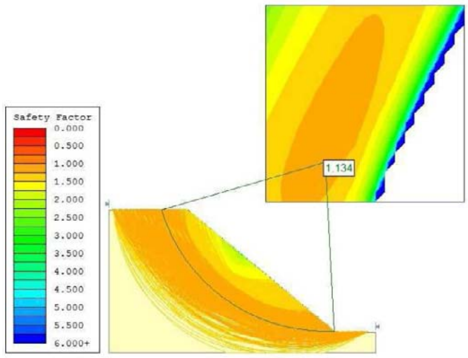

Fig.20. Janbu Method

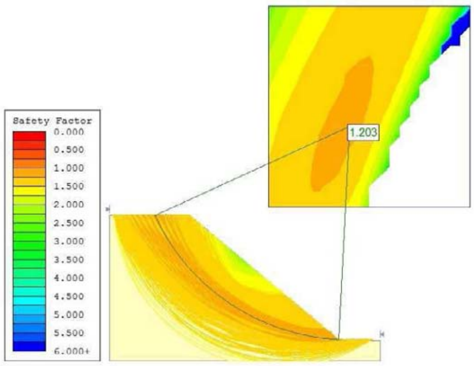

Fig.21. GLE Method

the varying slope angle and it has most sharp decrement in FoS at steeper slope angle. The trend observed by both the methods is more likely similar with a difference of 0.09 %.

The effect of slope height variation on FoS has also been plotted for Bishop and GLE method (Fig. 29). In both the methods, there is also an exponential decrease in factor of safety with increase in slope height for all three dump slopes. However, dump 1 shows more fluctuation in FoS against height while it increases from 31.5m to 51m which is mainly due to presence of tension cracks. Dump 2 & 3 shows sharp decrease in FoS due to high volume of overburden dump materials. The variability of factor of safety distribution for dump slope design along failure surface is mainly depend upon interslice shear force function and controlled by the properties of local dump materials.

PREVENTIVE MEASURES SUGGESTED

Based on the field investigation, laboratory experimentation and numerical simulation, some remedial measures have been proposed to minimize the dump failure. The study area experiences continuous mass movement particularly in rainy season and, needs proper attention to stabilize it. A proper drainage gallery and sealing of the cracks will prevent the water percolation in slope mass and

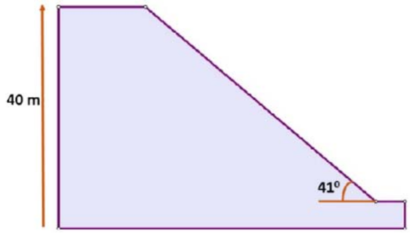

Fig.22. Geometry of the model for Location 3.

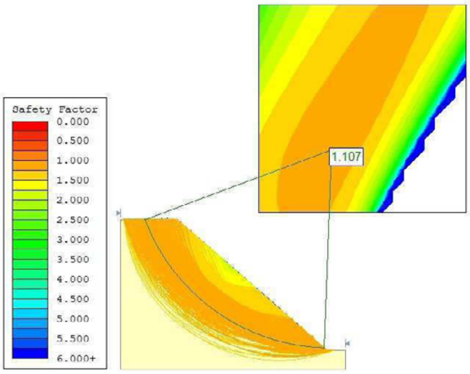

Fig.23. Bishop Method

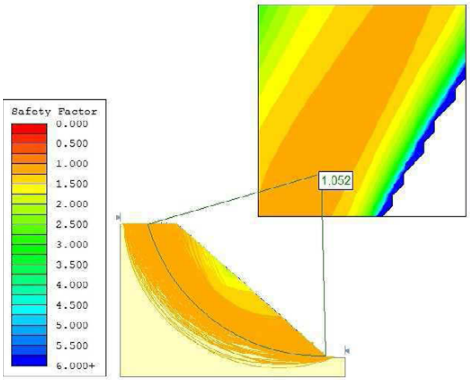

Fig.24. Ordinary Method

reduce the pore-water pressure, which will further improve the FoS. The height and slope angle of the dump slope has to be managed to reduce the slope failure. The proper dump management is require for suitable site selection and must

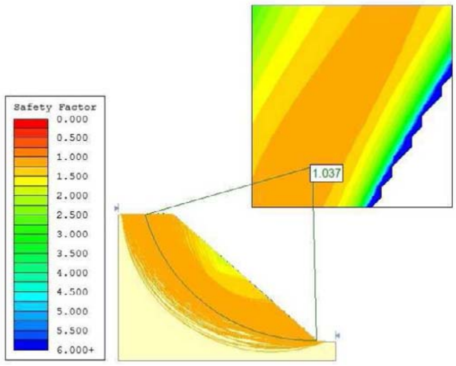

Fig.25. Janbu method

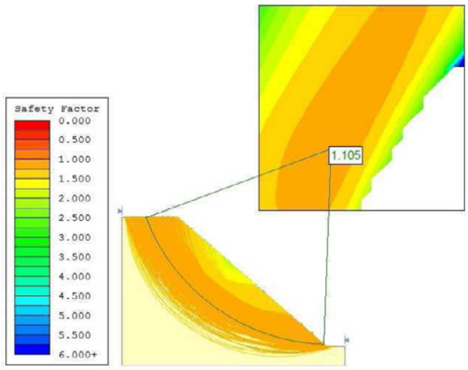

Fig. 26: GLE Method

ensure that there is no disturbance below the slope. The grass and tree reduce the stress concentration near the surface compare to barren slope (Chaulya et al. 2000), and implementation of bioengineering can also be used to stabilize the mine waste dump (Jian-long et al. 2005).

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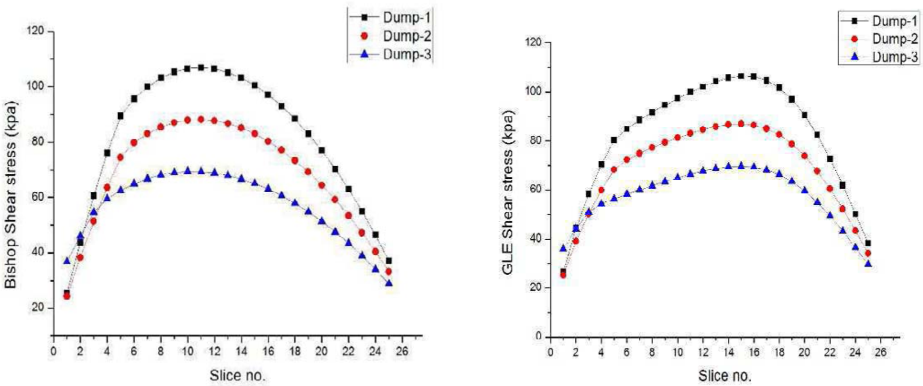

Fig.27. Shear stress vs. slice no of different dump slopes.

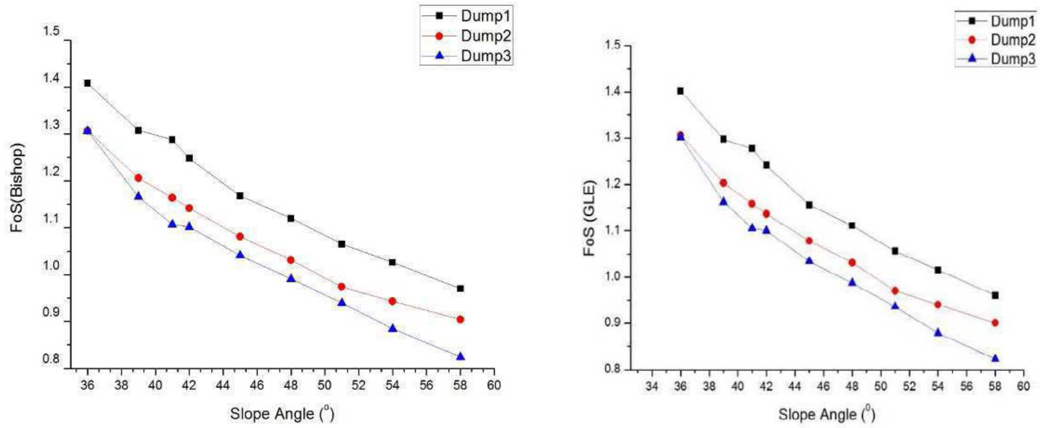

Fig.28. FoS vs. slope angles of different dump slopes

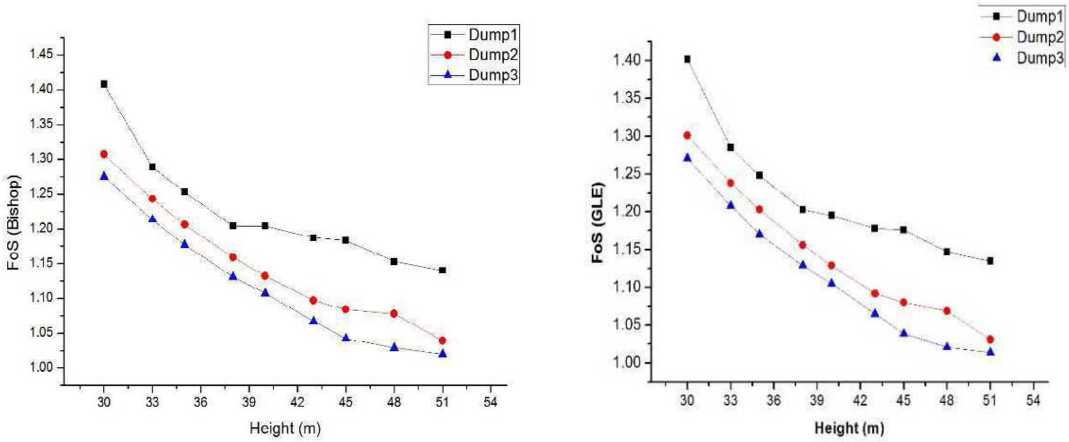

Fig.29. FoS vs. slope height of different dump slopes

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