A STUDY ON STABILITY ANALYSIS OF DUMPY SLOPE IN SURFACE COAL MINES

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ABSTRACT

India is the second largest producer of coal in the world. The amount of coal produced even in unprecedented times of COVID-19 is 730.87mt. in which opencast mining is predominant method for such production. It is believed that production of coal may increase by 15-20% by 2021-2022. Such statistics indicate that large amount of waste dump is generated and handled. Unless proper scientific and methodological ways for handling of waste is followed, it would impose complex problems of coal recovery, mine safety and mining cost.

Considering the major accidents, including disasters only due to slope failure, then there have been 23 accidents causing 143 fatalities from 1901 to 2016 (A.K. Dash). This statistic explains the importance of dump slope stability. The failure of dumps endangers men and machinery in a mine with a potential to cause catastrophic loss of life and property. Hence dump stability is critical in designing and functioning of any open cast mine.

This project aims to study stability of dump slope with varying and modeling of such failures using SLOPE/W software. The factor of safety of each varied parameter is calculated and modeled.

Keywords: Dump slope stability, Slope/w.

Objectives of the present work

The primary objectives of this project work are:

- To study in detail about different types of dump slope failure in mines
- To study and understand the basics of GEOSLOPE software
- To collect dump slope data and also geo-mechanical properties of the mine site
- To analyse factor of safety of dump slope numerically considering parametric study by varying input parameters, i.e., cohesion, angle of internal friction and radius of slip surface.

Description of the Mine

A Dump Failure of Mine A external OB dump was reported on2nd December 2009 with slumping of the crest and translation of the face. The spoil was displaced 70 m from the original location of the dump toe. At the time of failure dump number 1 was at its designed maximum elevation of 90 m and covered an area of approximately 78 hectares with approximately 3.4 Mm3 of spoil. Failure of dump number 1 directly impacted services (a road, power lines and drainage), endangered mine personnel and damage equipment. In addition to the failure of the dump material it was observed that the ground adjacent to the dump toe ‘‘heaved’’.

Mine Layout

Mine a is located in India and is worked by shovel dumper with an annual targeted production of 3.0 Mt and has 61 Mt of coal reserves. Three external OB dumps are located to the south of the pit. The trend of underlying strata is NW–SE with NE dips and consists of the Barren and Barakar formations from the Lower Gondwana Group of Permian aged rocks. Soils and alluvium occur to a maximum depth of 29 m. Mine A dump yard is immediately underlain by ‘‘black cotton soil’’ to a variable thickness from 8 to13 m. These soils include swelling clays of medium to high plasticity. These black cotton soils are expansive showing a marked volume change with changing moisture levels.

Geo-Studio: -

Geo-Studio is the one of the sophisticated geo-technical numerical modelling software, which enables us to analyze the practical solutions to realistic complex geo-technical issues, it earths science problems in the engineering sector. it is an integrated software which consist of various components as,

a) SLOPE / W b) SIGMA / W c) TEMP / W + TEMP 3D d) AIR / W e) SEEP / W + SEEP 3D f) QUAKE / W g) C TRAN / W h) BUILD 3D

Slope/w: -

SLOPE/W, in one form, or another has been on the market since 1977. The initial code was developed by Professor D.G. Fredlund at the University of Saskatchewan. The first commercial version was installed on mainframe computers and users could access the software through software bureaus. Then in the 1980s when

Personal Computers (PCs) became available, the code was completely re-written for the PC environment. Processing time was now available at the relatively low fixed cost of the computer, but computer memory was scarce and so the code had to be re-structured for this hardware environment. The product was renamed PC-SLOPE and released in 1983. Later in the 1980s it became evident that graphical interaction with PC software was going to be the wave of the future, and consequently a graphical CAD-like user interface was developed. The software was again renamed as SLOPE/W to reflect the Microsoft Windows environment and that it now had a graphical user interface. SLOPE/W was the very first geotechnical software product available commercially for analyzing slope stability. Currently, SLOPE/W is being used by thousands of professionals both in education and in practice.

Fig: The mine layout of Srirampur OCP-II

Overburden dump plans:

The details of year wise overburden removal are given in table no.1. A total quantity of 475.82 MCUM if hard overburden will be removed during 23 years of mining operations. In the initial years, the excavated OB will be dumped externally at predetermined location and the back-filling operations will commence only after sufficient decoaled area is available within the quarry.

Table: Showing the stage wise schedule of OB removal and dumping

S.No.	Stage at the end of	OB Removal (MCUM			Overburden including rehandling (MCUM)	Internal Dumping (MCUM)			External (MCUM)
		Top soil	OB	Total		in the quarry	Voids of OCP-I	Total	Dumping
1	1st Year (Box-cut)	0.950	18.630	19.580	19.580	---	---	---	18.630
2	6th Year	3.958	128.768	132.762	132.726	15.226	---	15.226	113.542
3	12th Year	6.427	282.701	289.128	290.396	86.327	---	86.327	196.347
4	18th Year	7.422	413.055	420.477	422.629	206.655	4.656	211.311	201.744
5	23rd Year	7.431	468.390	475.821	477.973	261.990	4.656	266.646	201.744

About 44% (208.889MCUM) of the total overburden removed will be dumped externally which includes the overburden (4.656 MCUM) dumped in the voids of Srirampur OCP-I. In an area of 246.42Ha raised to a height of 120m. The balance overburden i.e., 262.276 MCUM 66%) will be accommodated internally in the voids of Srirampur OCP-II. In an area of 269.18Ha raised to a height of 80m. The details of proposed dumping are as shown as figure-2 along with sections in figure-3. The following design criteria have been considered for the external and internal overburden dumps.

External Dump:

In order to avoid the soil erosion from the dump and also keeping in view the Godavari River, which is about 500m from the boundary of the external dump, the following design criteria have been considered:

1) Height of the dump in each deck will be 30m.
ii) Width of the berm will be 30 m.
iii) Dump slope in each deck will be maintained at 37.5°from the horizontal and overall
Slope of the dump at 25.6°

iv) Track dozers will be deployed for shaping the dumps
v) Maximum height of external dump is 120 m.

Internal Dump:

The following design criteria have been considered for:
i) Main OB to be dumped in 30 m high decks.
ii) 30 m berm width for allowing safe transport in each deck.
iii) Dump slope for each deck to be at natural repose of 37½° and overall slope of the dump at 28°.
iv) Track dozers to be deployed for shaping the dumps
v) Maximum height of internal dump is 80m above ground level.
vi) At the end of mining operations slopping of internal dumps will be made towards the Final void such that any soil erosion from the dumps will be settled in the voids.

The external dumps and back filled areas will be graded after reaching planned final height. Basing on the availability of the non-active dump zone, topsoil shall be spread over the OB dumps for taking up plantation. Based on the above features slope stability studies are done for the 120m height overburden benches the details of which are indicated below.

Table: The details of the proposed OB dump plans of Srirampur OCP – II

Benches	Bench Height (m)	Bench Width (m)	Reduced Level (m)	Angle of bench slope with respect to horizontal plane
1st	30	30	760	37.5^0
2nd	30	30	790	37.5^0
3rd	30	30	820	37.5^0
4th	30	30	850	37.5^0
5th	30	30	880	37.5^0

Site characteristics:

The stratigraphic succession indicates the coal measure rocks are a part of Barakar formation. Based on the lithological characteristics the sequences of coal seams as determined from the prospecting drill- hole data the over burden consists mainly sand stones of different grain size the details of which are presented in table-3.3.

Table: Showing lithological characteristics of over burden of Srirampur OCP- II

Strata	Lithology	Thickness (m)
Above I seam	Medium to coarse grain grey sandstones	45-75
Parting between I and II seam	Medium grained grey sandstones	10-36
Parting between II and III-B seam	Fine grained to Medium grained grey sandstones	25-50
Parting between III-B and III-A seam	Fine grained to Medium grained white sandstones	6-19
Parting between III-A and III seam	Fine grained white sandstones	9-35

The geo-mechanical properties of the over burden strata determined for the mines of SCCL for similar coal measure rocks are given below.

Table- Geo–mechanical properties of over burden of Srirampur OCP- II

Sl No.	Strata	Unit Weight kN/m^3 (Dry)	Compressive Strength (MPa)	Cohesion (C) kPa	Angle of Internal Friction (ϕ), (degree)
1	Medium to Coarse Grained Grey Sandstones	18.737	7.82	30	30
2	Medium Grained Grey Sandstones	20.78	17.9	25	40
3	Fine Grained Grey Sandstones	19.91	18.0	10	36
4	Coarse Grained White Stones	18.737	10.98	45	35.5
5	Fine Grained White Stones	21.28	23.48	10	42

As can be seen from the above the data the over burden rocks mainly comprised of sandstone for which the range of cohesion is 32 – 55 kg per square cm and the frictional angle is in the range of 30° to 42° the values are for intact rock, for residual rocks the values are much less. For example, friction angle for similar sandstone rock, the frictional angle is 25° to 34° (Hock. E-1970- Estimating the stability of excavated slopes in open cast mines.)

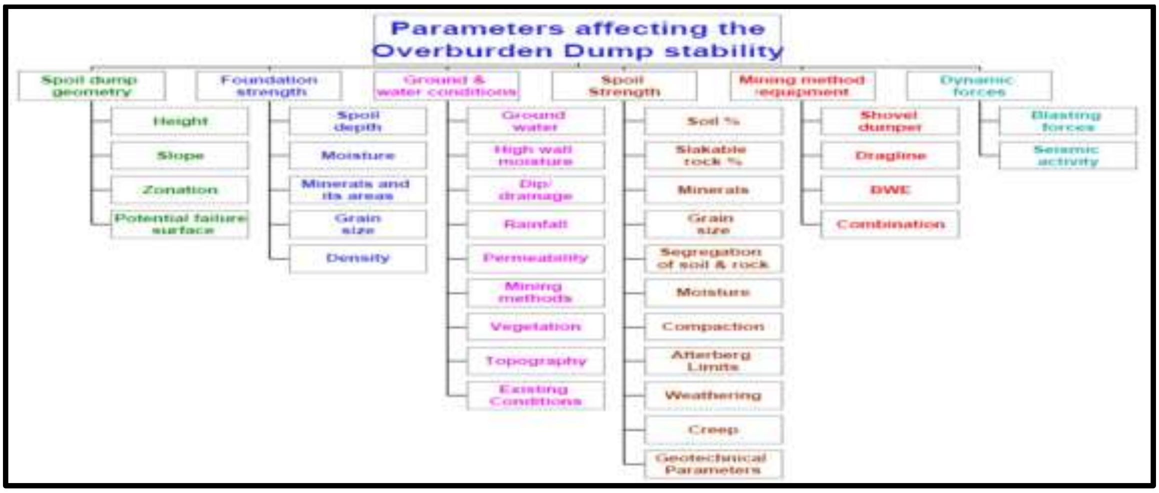
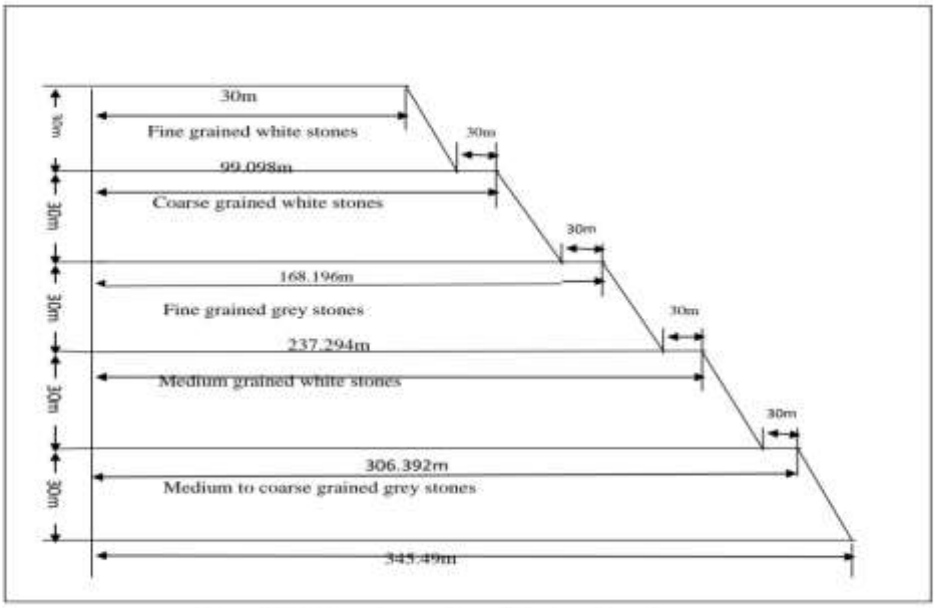


Figure: Factors affecting the overburden dump stability (Source: NCL)

Recommended Factor of safety

Classification of Dump	Recommended factor of safety	Name of Zone	Location of dump
a) During life open of quarry operation.	F.S. = 1.15 to 1.20	Low risk	100m away from working coal bench.
	F.S. = 1.3 to 1.35	High risk	100m within working coal bench.
b) After the end of quarry life, i.e., abandoned quarry Operation.	F.S. = 1.3 to 1.35	High risk	100m within working coal bench.
	F.S. = 1.15 to 1.20	Low risk	100m away from working coal bench.



2D Numerical Model considered for the study

Geo-technical parameters

Bench no.	Unitweight (kN/m^3)	Cohesion (kPa)	Angle of internal friction in degrees
1	18.737	90.5	30
2	20.79	95.8	40
3	19.91	105.8	36
4	18.737	108	35.5
5	21.28	94.3	42

Cohesion vs factor of safety

Cohesion(kPa)	10	15	20	25	30
Factor of safety	1.571	1.638	1.705	1.772	1.829

Variation of factor of safety with angle of internal friction

The following table describes variation of factor of safety with angle of internal friction, which consists of 5 iterations (5 models) with a uniform interval of 5^0. The corresponding model is shown in below section angle of internal friction vs factor of safety.

Angle of internal friction vs factor of safety

Angle of internal friction (in deg)	15	20	25	30	35
Factor of safety	0.868	1.107	1.362	1.638	1.944

Variation of factor of safety with unit weight

The following table describes variation of factor of safety with unit weight, which consists of 5 iterations (5 models) with a uniform interval of 5 KN/m^3. The corresponding model is shown in below section unit weight vs factor of safety.

Unit vs factor of safety

Unit weight (in KN/m^3)	5	10	15	20	25
Factor of safety	1.624	1.311	1.181	1.115	1.076

Angle of internal friction vs factor of safety

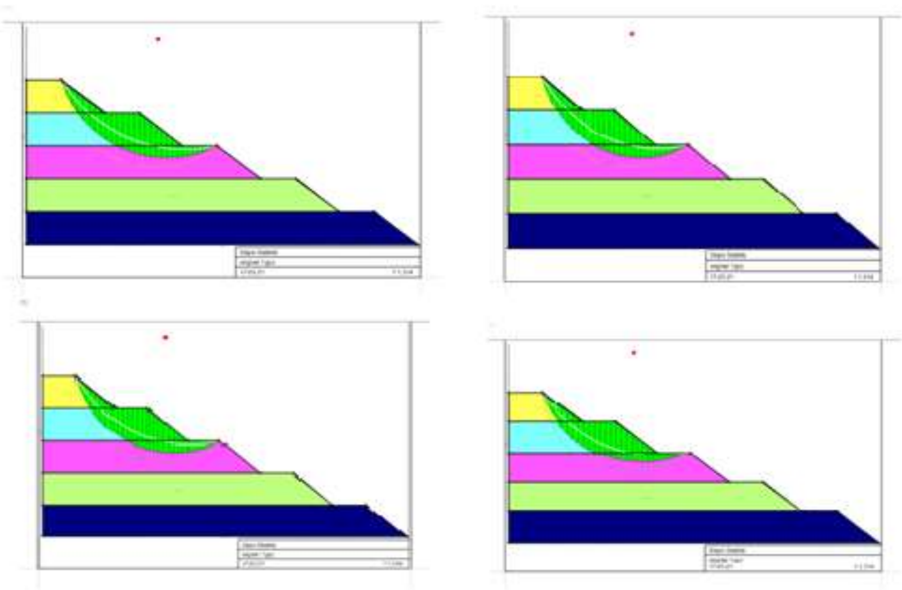
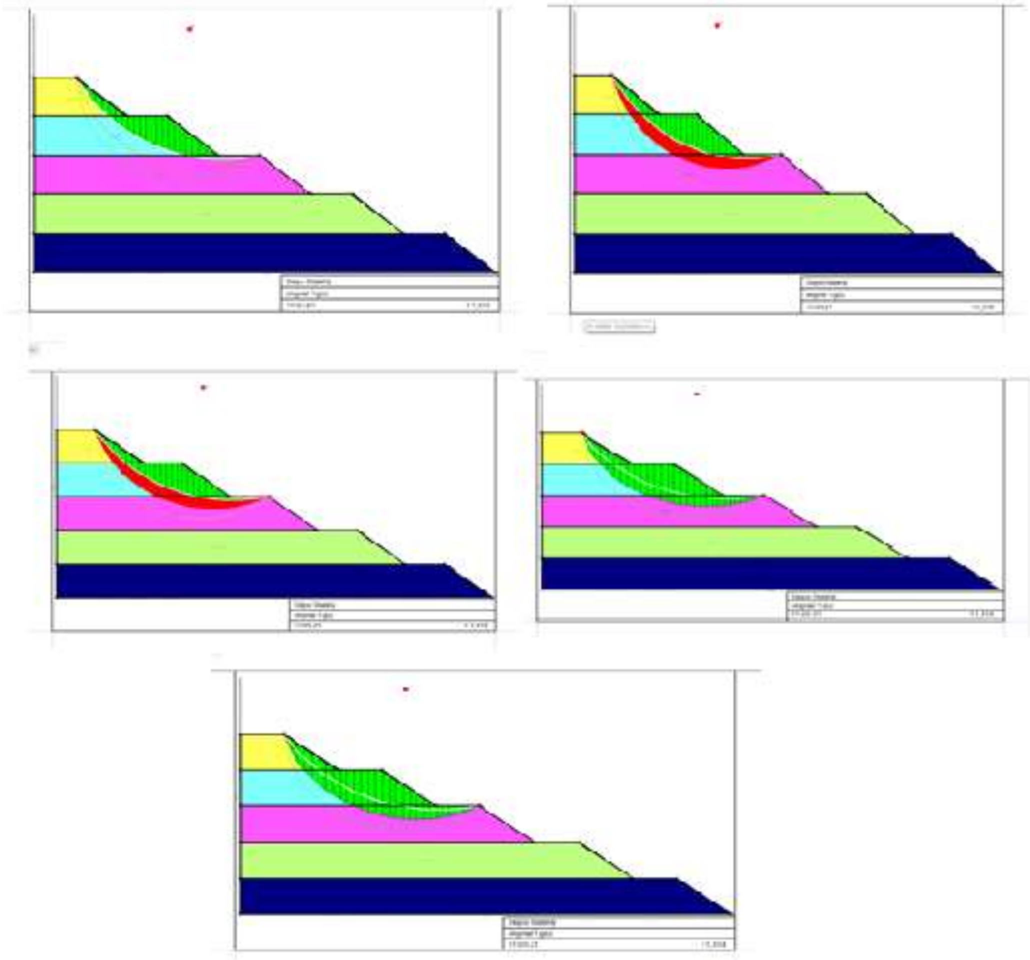
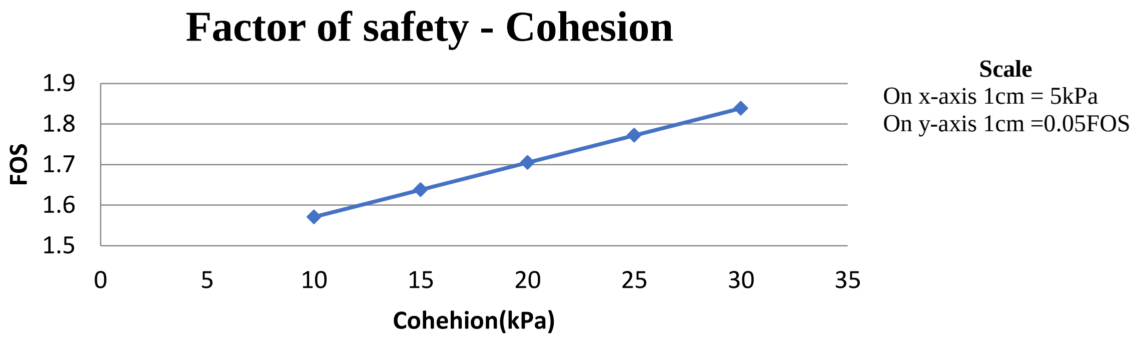


Fig: Models which depicts angle of internal friction vs factor of safety analysis by SLOAP/W software

Cohesion vs factor of safety





Factor of safety vs Cohesion

Fig: GRAPHICAL REPRESENTATION OF ANALYSIS OF FACTOR OF SAFETY WITH RESPECT TO COHESION

- The above figure shows the influence of cohesion on the overall FOS of the dump slope, it is determined by a series of analysis carried out by varying the cohesion of the geometrical slope for analysis 5 different values (10,15,20,25 & 30 kPa) were considered, while all other parameters were kept constant.
- It evident that from the graph the is almost linear increment of FOS with the cohesion has been obtained, it may explained by the statement that the shear strength of the material has the linear correlation with the cohesion of soil. Therefore, the FOS is directly proportional to cohesion.

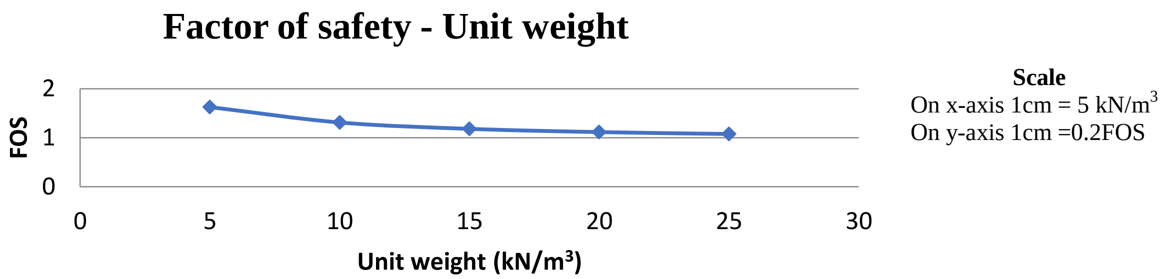


Fig: Graphical representation of analysis of factor of safety –unit weight

- From the above graph the influence of unit weight on the FOS is determined by carrying series of analysis by varying 5 different values of unit weight (5, 10, 15, 20 & 25 kN/m^3) we can conclude that the FOS is inversely proportional to unit weight.
  As the unit weight of the material acts downwards in the direction of the gravity due to which the material tends to slide along the dump slope. With the increasing of unit weight, the shear strength of the material gets reduced.

ONCLUSION AND FUTURE SCOPE OF WORK

Conclusion

Based on the analyses made from the project, following recommendations have been made to ensure the stability of the slope.

1. The factor of safety of the slope under dry condition is 1.6.
2. The factor of safety for the existing slope is 1.55 for 10kPa of cohesion and increases with increase in cohesion.
3. The factor of safety for the existing slope is 0.8 for 15^0 of angle of internal friction and increases with increasing angle of internal friction.
4. The factor of safety for the existing slope is 1.6 for 5 KN/m^3 of Unit weight and factor of safety decreases with increasing unit weight.

Future scope of the work

The work conducted in this study can be extended further considering the following studies:

1. The present study did not consider pore water pressure while analysing the dump slope stability. However, in actual scenario, it may be present. Hence, it can be included in future study of work.
2. This study only dealt with input parameters such as cohesion, angle of internal friction and unit weight into consideration. In future, more parameters can be included such as bench height, slope angle and grain size.
3. The present two-dimensional simulation can be extended to three-dimensional considering effect from the other direction, which will clearly depict the stresses, strains and factor of safety in the multi-dimension.
4. Rock mass failure criterions such as Drucker-Prager model and Mohr-Coulomb model can be used to incorporate non-linear elasto-plastic conditions to analyse the equivalent plastic strains at failure zones.

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