Failure investigation of internal dragline dump slope - A case study

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ABSTRACT

The stability of internal mine waste dump is plays an important in the economics and also safety point of view. The failure in internal dump slopes leads to loss of life, production and serious impact on surrounding facilities. The internal dumps are usually consisting of a mixture of fragmented rocks and loose material. The present paper discussed the failure case of internal dragline dump of an opencast mine "A" using limit equilibrium and finite element method. The failed dragline overburden dump found to displace the coal rib along with overburden material approximately 80m from the original location of toe of the coal rib. The location of failure plane has been determined and found to be through the base of the coal rib left adjacent to the dragline dump during extraction of coal.

Keywords: Mining, Opencast, Dragline Dump, Internal dump Slope, Numerical Modeling

1 INTRODUCTION

In India, 606.89 MT coal has been produced in the financial year 2018–2019 by Coal India Limited (CIL), out of which 95 % is from opencast mines (CIL, 2019). Management of internal overburden dump is very important for the running mine successful mine. The improper management of dump can cause instability, which can lead to failure of dump and hamper coal production from the mine. Opencast mining operated with dragline is a very efficient method for the extraction of coal with high productivity and low operational cost. Fig. 1 shows a typical layout of internal dumping by dragline as well as increased dump height by shovel dumper combination (Rai, et.al 2012). The overburden is removed by dragline and dumped inside the pit creating an internal dump. While extracting the coal exposed by Dragline, a coal rib is left between the dragline dump and mine benches. The waste material is dumped in de-coaled area behind the coal rib. Waste rock from upper benches, being worked by shovel-dumper combination, is dumped over the dragline dump maintaining about 200m distance from the current dragline dump in progress.

The stability of a dragline dump supported by a coal rib depends on various parameters, such as the shear strength of the coal rib and dump interface, the dimension of the coal rib i.e. thickness of coal rib at the top and its base, the distance of bench from the coal rib, the height of the dragline dump, etc. Coal rib is left to ensure stability of internal dump and keep the corridor free for transportation and also acts as a support for the dragline dump. The coal rib restricts the movement of the dump and helps in the placement of the maximum possible overburden material in the mined out area. Subsequent build-up of high horizontal stresses in the rib, either due to accumulation of water or due to over dumping, causes the rib to fail which can lead to the dump failure. If the coal rib fails, the overburden can flow into the working area which may cause catastrophe to men, material and equipment. The important factors which are liable to slope failure of internal dump:

- Over-steepening of the internal dump by dragline
- Water accumulated behind the coal rib
- Reductions in the interface shear strength between foundations and dump material due to water.
- Less than 200m distance between dragline cut and dumping by shovel-dumper over the previous dragline dumps.
- Inadequate dump material strength

Shear Strength of the overburden dump is purely frictional strength during initial stage (commonly found to be between 35^0 to 40^0). The cohesion increases from 0 to 100 kPa during subsequent compaction from self-weight and the dynamic movements of machinery. This compacted material can be re-excavated to stable slopes of 40^0 to 60^0 (Rosengren et al., 2010). However with saturation of the overburden dump material the frictional shear strength may reduce to as low as 14 (Rosengren et al. ,2010) in the lowermost 5m of dump material (Simmons, 2013) and the stability of this basal zone or interface face may control the overall large-scale dump stability.

Failure of an improperly designed dump is likely to result in damage to mining equipment, personnel injury and loss of production. Numbers of cases have been reported where failures of the coal rib of internal dragline dumps have caused substantial damage and have interrupted production (DGMS Circular 2010; Kasmer et al. 2006 and Fossil 2006).

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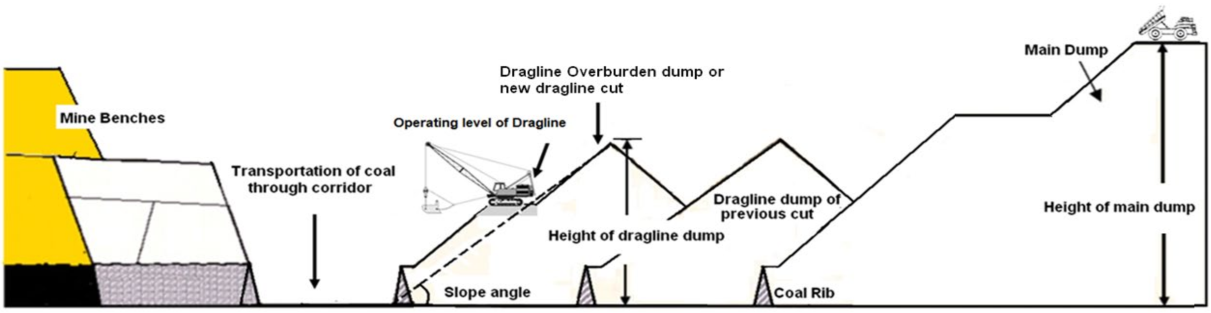

Fig. 1: Typical layout of internal dragline dump with mine benches (Gupta, et.at 2014)

The present paper discusses one of the failure case of internal dump and coal rib of an Indian coal Mine A of Singrauli coal field. This paper investigates the probable mechanism of the overburden dump failure at Mine A using numerical tools and highlights the possible causes of internal dump slope failure.

2 INTERNAL DRAGLINE DUMP FAILURE

Failure of Internal dragline dump was reported on in Dec 2008 with movement of coal rib and dump mass in mine A. The coal rib was displaced 80m from the original location (Fig 2). At the time of failure internal dump was designed for maximum height of 84m. The portion of the dragline dump measuring 135m (length) x 70m (height along the side of the slope) and 6x19m (height across the slope) failed and trapped five persons and buried a shovel at its bottom (DGMS, Circular 2010).

Golder and Roy (2017) performed various laboratory tests and assessed the shear strength of dump material. The main reason behind accident was found sudden failure of waste dump which was situated near to working area of mine operators. The slope failed suddenly with fast movement of dump material. The coal rib was located near to high wall along with the machineries after failure.

Singh (2010) analyzed the failed case study of internal dump of Jayant OCP. Samples were collected and determined the shear strength of dump material. It was concluded that the saturation of dump slope base due to presence of coal rib, cross cut and dumb bell, non-existence of planned corridor width at dragline sitting level and dumping of overburden re-handled from dumb-bell by dragline over the dragline dump could be the main reason of failure Singh (2010).

Sharam et. al., (2015) identification of failure surfaces in various dragline dumps of opencast coal mines of Singrauli area. The different failure pattern and modes were identified within the overburden dragline dump masses. The various geotechnical properties of different dragline dumps have been determined. The failure surfaces in the overburden dragline dumps followed circular and circular-cum-planar paths depending upon the mine

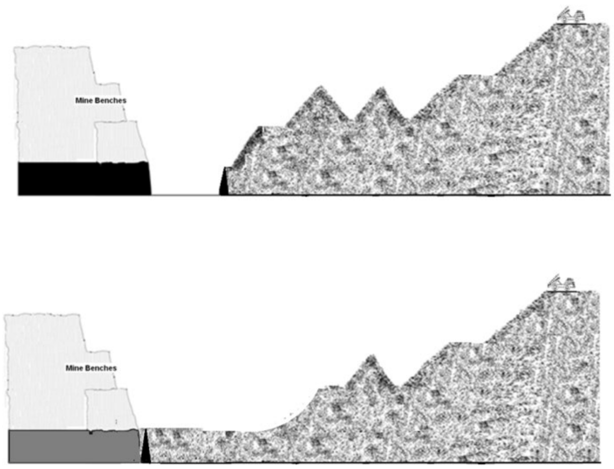

Fig. 2: Condition of coal rib after the failure of internal dragline dump

2.1 Geology and geotechnical properties

The Mine A experienced fatal accident of 5 mine employees in December, 2008. The main reason behind accident was sudden failure of waste dump which was situated near the working area of mine operators. Table 1 shows the material properties used for simulation of dump slope of Mine A. The data has been obtained based on laboratory investigations and from literature. Mine A is a mechanized open cast coal mine and located in the south-eastern part of Mohar sub-basin of Singrauli coalfield. The method of mining is opencast system of mining deploying dragline and shovel-dumper. There are three workable coal seams occurring in this block, of which the lower most Turra seam is of high potential. The average thickness of Turra seams is 21-24 m, Purewa Bottom seam is 12 m and Purewa Top seam, is 4-6 m.

The soil and the overburden strata above the roof of Turra seam comprises mainly of sandstones, shales and clay. The rock immediately below the soil cover is found to be weathered and is weaker than the strata. The strata below Turra seam which is also the floor of the mine is generally composed of medium to fine grained sandstone.

The dragline is handling overburden of 70 m cut width and side cast into exposed coal floor of Turra seam and a coal rib was left to support the dragline dump. Height of dragline side-cast dump in the proposed system is generally 60m. Above the dragline dump, waste material was to be stacked tier by tier and height of each such tier design should not to exceed 30m. A clearance of 140m was proposed between latest dragline dump crest and immediately next dump tier. Lag between two tiers of dump was proposed to be preferably not less than 80 m. The details of parameters before failure is shown in table 2.

Table 1: Geotechnical properties of dump material, coal rib and Interface (Golder and Roy 2017 and Singh, 2010)

Material Properties and Type of Material	Cohesion (kPa)	Friction angle (degree)	Density gm/cc
Overburden	75	25	2.2
Dump Base with high moisture content	38	20	2.17
Foundation	0.1	30	2.6
Coal	130	30	1..3
Coal Interface	140	30	-
Dump interface	10	20	-
Rock	3.0	35	2.5

3.0 NUMERICAL MODELING OF DRAGLINE DUMP SLOPES

3.1 Limit equilibrium Analysis

In the present study, limit equilibrium method (LEM) has been used to compute the factor of safety using bishop method. The critical slip surface has been calculated for above method having the lowest factor of safety.

The conventional limit equilibrium method is used in many geotechnical practices to investigate and analyse the stability of slope. The method assumes that the shear strength of the material along the potential failure surface are governed by Mohr-Coulomb failure criterion. The most common methods for limit equilibrium analysis for slope stability is method of slices. The soil mass above the assumed slip surface is divided into vertical slices for purpose of analysis. Several different methods of slices are available for analyzing the circular and non-circular failure condition.

Table 2: Input Parameters for simulation for Mine A (Singh, 2010 and Sharam et. al., 2015)

Sr. No.	Input parameters	Value
1	Overall height of dragline dumps	84 m
2	Slope of below dragline dump	45˚
3	Height of slope below dragline dumps	42
4	Slope of dragline above dragline dump	37
5	Height of slope above dragline dump	24
6	Height of main dump	150 m
7	Coal rib height	17 m
8	Coal rib base width	10 m
9	Coal rib top width	5 m
10	Number of dragline dumps	2
11	Dip of seam	3˚

The initial study was undertaken using LEM and properties using as shown in Table 2. The location of minimum stability is the coal rib with a failure surface extending from the top slope of dragline dump toe. The factor of safety is 1.273 which indicates the dragline dump slope is having short term stability (Fig. 3).

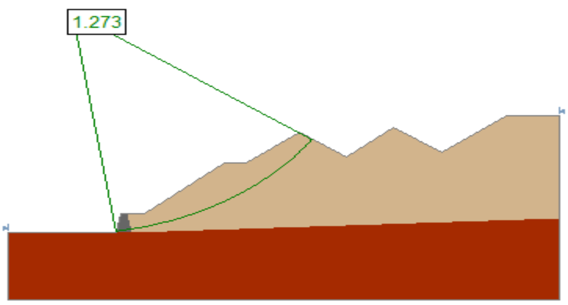

Fig. 3: factor of safety by limit equilibrium method

3.2 Finite element Analysis

Continuum methods such as, finite element and finite difference methods allow consideration of a variety of factors that influence the distribution of stresses and strains within the modelled domain. These include excavation and construction forces, non-linear stress strain relationships including the failure in shear or tension of the bulk material, strain localisation and movement on joints or planes of weakness. Finite element analysis is carried out to investigate failure using phase 2 software that uses strength reduction technique.

A typical discretised view of the base model is shown in Fig 4. The model is simulated based on data given in table 3. The base width of coal rib 10 m and top width of coal rib is 4 m and the distance of dragline bench from the coal rib is 12 m. The model is discretised in quadrilateral shaped elements and joint interface is used to take into account the behaviour of the interface between floor and dump or floor and coal seam. Overburden dump is created and analysed under gravitational load with roller boundaries specified on the base and two sides. The coal rib is discretised with fine mesh with element size of 0.2m in order to increase the accuracy of analysis.

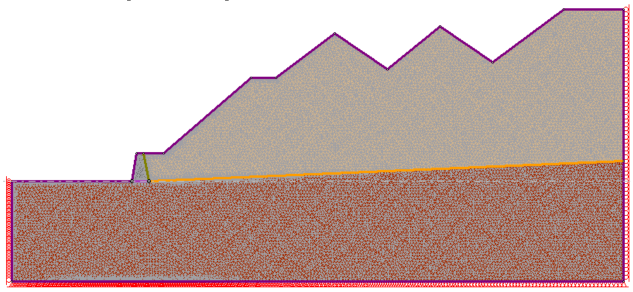

Fig. 4: Typical discretized view of internal mine dump and Coal Rib

Results from the numerical modeling predict that failure is initiated at the toe of the dump at nearly same location as the minimum factor of safety predicted from the initial circular LEM studies.
In the limit equilibrium the failure circle is just passing through the coal rib. It means during the failure the coal rib could have also failed. However, investigation of the failure of mine A indicates that the coal rib was found intact near the high wall.

From the study it is understood that the failure circle is passed from the interface between coal rib and foundation and also interfaces between the dump material and foundation (Fig 5). Therefore, the both the interfaces play important role in stability of dragline dump.

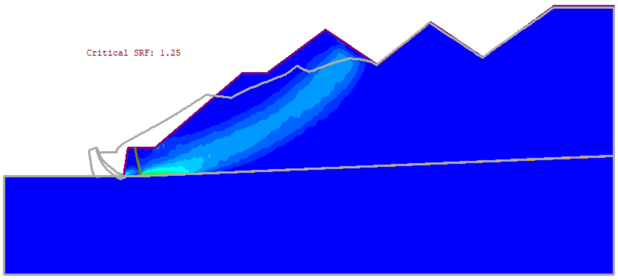

Fig. 5: Maximum shear strain plot of the base model of internal dragline dump

In the next simulation the height of main dump increased to 150m. The results are same as in previous case with less height of main dump (Fig 6). When the height of main dump is increased to 90m and 150m, the location of failure circle found to be nearly same. Therefore, it can be understood that there is not much role of the height of main dump material on failure pattern in the present case.

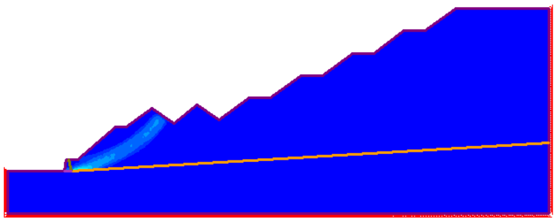

Fig. 6: Maximum shear strain in the main dump when height is increased

The angle of dragline dump has been increased to 60^0 and model is simulated. The deformation boundary has been plotted and it is observed that the coal rib is trying to overturn. However, it is observed from failure of mine A that the coal rib is not overturned but it got displaced from toe of the dump to high wall benches (Fig 7).

When the interface strength between dump material and foundation has been reduced the extent of failure circle reduced and there is a tendency of toppling of coal rib (Fig 8). In next simulation the interface between coal rib and foundation has been reduced. It is found that the coal rib is displaced and not toppled (Fig 9). That means the failure is initiated from the base of coal rib.

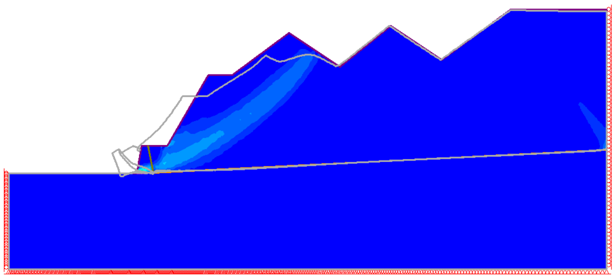

Fig. 7: Plotting of deformation and maximum shear strain with increased dragline slope angle

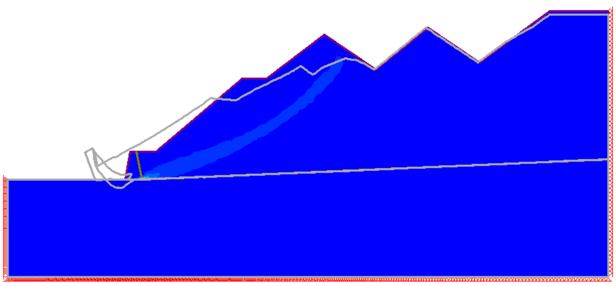

Fig. 8: Plotting of deformation and maximum shear strain at very low dump interface

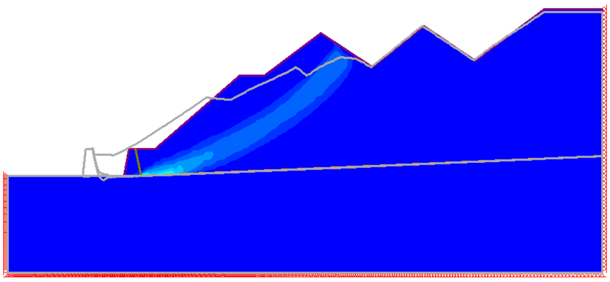

Fig. 9: Plotting of deformation and maximum shear strain at very low shear strength of coal interface

The relation between shear strength of interface between coal and foundation has been varied and factor of safety is calculated and plotted in Fig 10. It is found that the factors of safety is reducing but do not to fail drastically. It means that the failure is not sudden even if the interface between coal and foundation is failed.

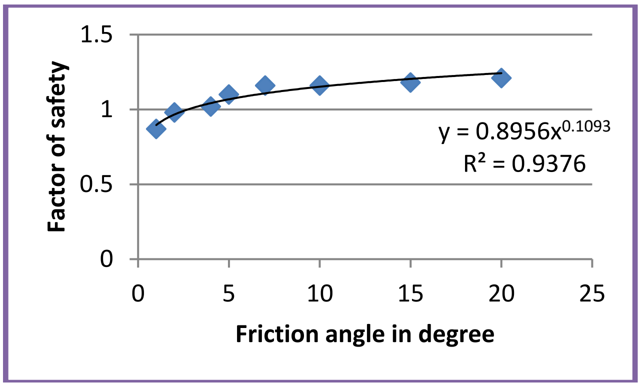

Fig. 10: Relation between coal interface shear strength and factor of safety

Therefore, the water pressure is applied at interface between coal rib and dump foundation. The factor of safety is less than 1. The model is not solved and iteration converge was not converged. It indicates that the dragline dump slope failed due to high horizontal pressure on coal rib due water present behind the coal rib and failure of interface of coal and dump are the main reason for the dragline dump failure.

4. CONCLUSION

The study is based on failed case study of a large open cast coal mine where, coal ribs were left to protect the overburden dump slope. The draglines are worked for a bench height of 40–55m for overburden removal Numerical methods including limit equilibrium and finite element methods have been used to simulate the dragline dump in various scenario to highlights the possible causes of internal dump slope failure of Mine A. This study of Mine A overburden dump stability indicated that the interface strength and water were fully mobilized and provided a slip surface for the overlying dump material and coal rib.

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