Safety aspects of large dragline-operated opencast mines – An overview

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Synopsis

The Jayant opencast operation is one of the largest opencast coal mines in India. Prior to 2008 the mine experienced a number of dragline dump failures, which was a major hindrance in sustaining production. Northern Coalfields Limited (NCL) and the mine management engaged several design, research, and academic institutions to carry out dump slope stability studies, particularly of dragline dumps. Birla Institute of Technology prepared a report on the investigations in May 2009. In this paper we review the findings of the report and the measures taken to tackle the safety aspects of dragline dumps.

Keywords

slope stability, circular failure, opencast mining, shear strength, overburden dump.

Study area

The Jayant Project of Northern Coalfields Limited (NCL) is situated in the Madhya Pradesh district of Sidhi in the Singrauli Coalfields. The location of the project is latitude 24° 05'45" to 24° 11' 25" N and kongitude 82° 38' 21" to 82° 40' 45" E, as per Indian Survey toposheet no. 63 L/12. The Shaktinagar rail station on the Chopan-Katni line of the East Central Railway is approximately 5 km from the project (CMPDI, 2007).

The area of the Jayant Block in the northeastern section of the Singrauli Coalfield is 11.10 km^2. The Jayant opencast operation of the project is located on a hilly plateau with the RL varying from 390-430 m.

The total net geological reserve is 305.50 Mt, while the mineable reserve is 282.71 Mt (as at 31 March 2018) and thus the overall volume of overburden with a common stripping ratio of 2.60 m^3/t is 907.20 million m^3. There are three different seams present in the Jayant Block, *i.e.*, Turra Seam, Purewa Bottom Seam, and Purewa Top Seam as shown in Figure 1 (Singh *et al.*, 2014; Sharma and Roy, 2015).

In this area, most of the overburden is medium-grained to coarse-grained sandstone, carbonaceous shale, and sandy shale. The the dragline dump is situated on shale and sandy shale that provides a competent foundation. The floor of the dump is covered with a thin layer comprising a wet mixture of coal dust, carbonaceous shale, and sandstone (Singh *et al.*, 2012), and fragments of waste rock, which is referred to as interface material. Two types of circular failure surfaces are envisaged as shown in Figure 2.

➤ Failure within the material of dump
➤ Failure within both the dump material and interface material.

Hydrogeological factors

The hydrogeological parameters that control the stability of the dump are determined as follows.

➤ An attempt was made earlier to delineate or establish the water table/phreatic surface within the dump by installing piezometers. However, the piezometers could not be installed due to difficulty experienced in drilling through the loose, fragmented, and heterogeneous dump material.
➤ In the absence of sufficient hydrogeological data, the position and curvature of the phreatic surface inside the dump, as well as the seepage height above the dump toe as shown in Figure 3, was observed visually and reported by mine officials during rainy seasons.
➤ It is not feasible to evaluate the phreatic surface in the dragline dump using piezometers because the soil is heterogeneous. The water table height (H_w) is estimated by Casagrande's equation (Murthy, 2002; Sengupta and Roy, 2015; (Moosavi, Shirinabadi, and Gholinejad, 2016).

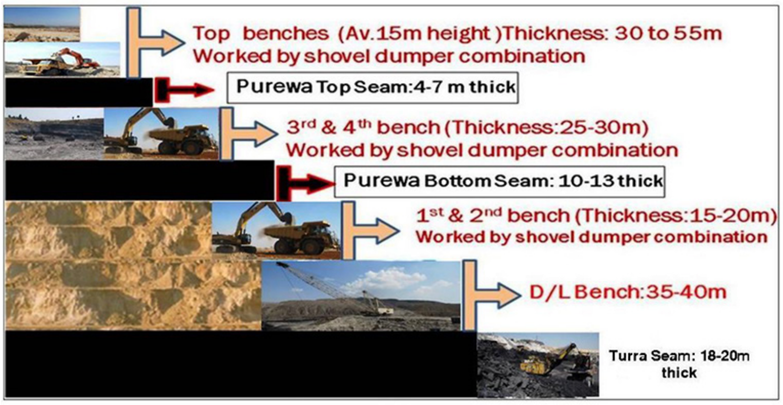

Figure 1—Geological cross-section of the Jayant opencast mine (Sharma and Roy, 2015)

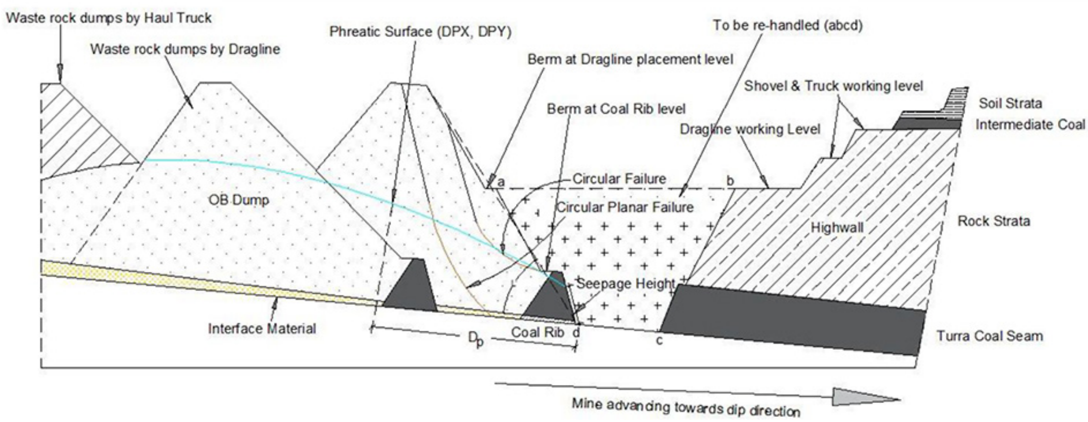

Figure 2—Schematic diagram of dragline working (Sharma and Roy, 2015)

$$P_a = D_p / \cos\beta - \sqrt{[(D_p / \cos\beta)^2 - (H_w / \sin\beta)^2]}. \quad [1]$$

where

P_a = Height of seepage at the toe of the dump.
L or β = Overall angle of slope of dump.
D_p = Behind the toe of dump *i.e.*, 60 m.

By applying Casagrande's equation, at a distance of 300 m from the toe of the dump the height of the phreatic surface within the dump is calculated as tabulated in Table I.

With this height of water table, the seepage and hydrostatic forces are calculated and considered in the stability calculation.

The phreatic surface (DPY, DPX) (Figure 2) is also evaluated through relevant condition:

$$DPY(J) = \sqrt{[(DPX - P_a \times \cos\beta / 2) \times 2 P_a \times \sin\beta \times \tan\beta]} \quad [2]$$

The height of the water table is calculated as 25 and 36 m (Table I).

Table I

Height of water table corresponding to different seepage heights

Seepage height (P_a) (m)	Height of water table (H_w) (m)
3	25
6	36

The height of seepage face is shown in Figure 2

The upward thrust of the water can be defined as the product of the unit weight of the water and the volume of the dragline dump submerged under the water table within the failure mass (Roy, 2016)

The seepage force is calculated as the product of the upward thrust and the sine of the gradient of the horizontal phreatic surface (Murthy, 2002; Sengupta and Roy, 2015) (Figure 4).

Seismicity and blast vibrations

Seismic forces are regarded according to the Indian Standard criteria for earthquake-resistant structural design (5th edn) IS 1893:2002 (IS-1893 (part 1), 2002). The horizontal seismic coefficient (A_h) design for the Jayant dragline dump is determined by the following expression (Sengupta and Roy, 2015):

$$A_h = ZIS_a / 2Rg \quad [3]$$

where

Z = Zone factor (study area is located in zone III according to IS 1893:2000)
I = Importance factor
R = Response reduction factor
Sa/g = Average response acceleration coefficient of dump mass.

According to the Indian seismic map, the project is located in zone III, with the horizontal seismic coefficient of 0.02 m/s², as per the IS code considered here. The blast vibration coefficient on the dump mass due to ongoing blasting was estimated such that the horizontal coefficient of 0.04 m/s² will include both seismicity and blasting (Mosinets and Shemyakin, 1974).

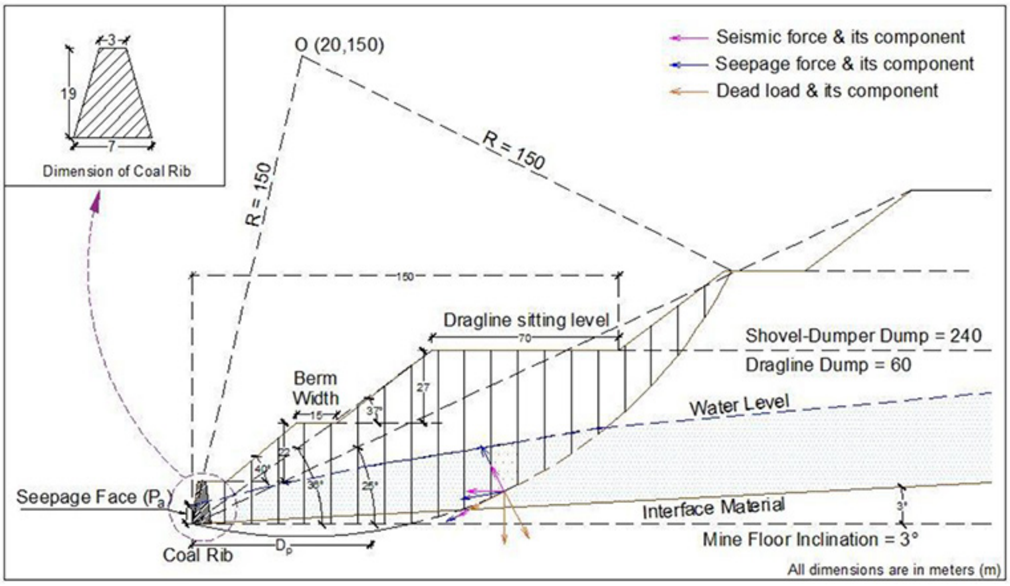

Figure 3—Circular planar failure surface at Jayant mine

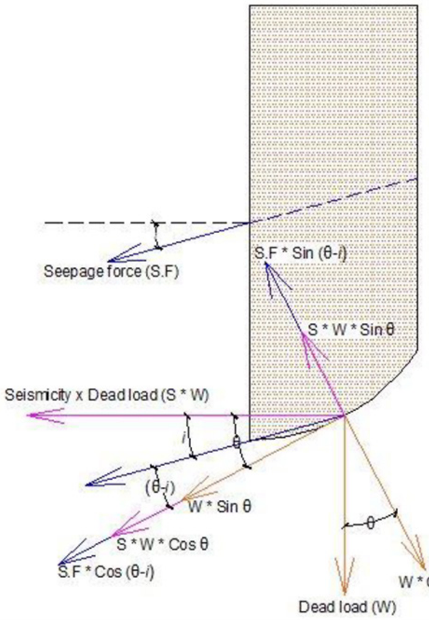

Figure 4—Free body diagram of individual slices. *W* - dead load of slice, *i* - sine gradient, *S* - seismicity factor

Dump floor inclination

The mine floor inclination varies from 2° to 4° (CMPDI, 2018). For stability calculations a dump floor inclination of 3° is considered here (Sengupta and Roy, 2015).

Dragline dump height

The dragline dump height, which varies between 60 to 100 m, and the surcharge load of the shovel dump on the dragline dump are also considered in the stability analysis (Mosinets and Shemyakin, 1974; Zaitseva and Zaitsev, 2009; Sengupta, Sharma, and Roy, 2014).

Coal rib

According to existing practice in this mine, a coal rib of 7 m base width and 3 m top width with average Turra seam thickness of 19 m, as shown in Figure 3, is considered as a resisting force against dump failure (Roy, 2003). The coal rib left at the toe of the dump acts as a retaining wall and reduces dragline dump re-handling to some extent (Colwell and Mark, 2003; Besimbaeva *et al*., 2018).

Laboratory tests for the generation of geotechnical information

Samples of the dump material as well as the interface material were collected and transported to BIT Mesra for determination of the strength parameters (Ranjan *et al*., 2017) (Table II).

Recommendations

Considering the above parameters and by applying both Fellenius and Bishop's simplified method (Moosavi, Shirinabadi, and Gholinejad, 2016), the slope angles for the dragline dump are calculated (Table III) and recommended for a minimum factor of safety of 1.20 for different heights of the seepage face (Besimbaeva *et al*., 2018).

Table II

Shear strength parameters determined by laboratory testing (large shear box apparatus)

Parameter	Dump material at natural moisture condition	Interface material in submerged condition at the base of the dragline dump	Interface layer separating the coal rib/barrier
Cohesion (kN/m²)	75	40	155
Angle of internal friction (°)	25	21	35
Bulk density (kN/m³)	20.6	Not required in calculation	16

Table III

Prediction of dragline dump geometry

Height of dragline dump (H) (m)	Overall slope angle of the dragline dump (°)as shown in Figure 3	
	Seepage height of water (P_a) = 3 m, and height of water table (H_w) = 25 m (Figure 3)	Seepage height of water (P_a) = 6 m, and height) of water table (H_w) = 36 m (Figure 3
60	33	31
70	32	30
80	31	29
90	30	28
100	28	26

The results are documented for different dragline dump geometries in Table III.

The angle of repose of the dragline dump is the overall angle with respect to the horizontal plane over which it is standing. The dragline dump is considered to be cohesionless for the purpose of determining the angle of repose, although in reality the dump has an emerging water table, an inclined floor, pore pressure within the dump material, and is affected by blast vibrations and pore pressure within the dump material. Also, cohesion is generated due to the compaction of the dump material under its own weight. Hence the angle of repose of the dragline dump is 37° in the ideal case, but in actual site conditions owing to the above prevailing geo-engineering considerations the overall slope of the dump will differ.

The above recommended slopes of the dragline dump are maintained by optimizing the following parameters of the dump profile as shown in Figure 3.

- ➤ At the mining level of the dragline – berm width
- ➤ Berm width present at coal rib/barrier
- ➤ Angle of slope below mining level of the dragline.

It is recommended that truck and shovel dumps overlying the dragline dump are formed 120 to 150 m away from the toe of the dragline dump (Sharma and Roy, 2015), (*i.e.* the interval between the toe of the dump formed by the shovel dump and dragline dump should be at least two cut widths 120–150 m). In this case, the dragline dump will act as a foundation for the shovel dump. Hence, the geotechnical properties are considered to be the same for both the shovel dump and its foundation. Accordingly, the following combinations of shovel dump are calculated and recommended (Government of India, 2017; Directorate General of Mine Safety, 2008) in Table IV and shown in Figure 3.

The recommended overall slope angle of the shovel dump can be maintained by adjusting the berm width at the coal rib roof level.

Precautionary measures

In addition to managing the slope, several proposals are suggested and implemented to ensure the stability of internal dumps as well as dragline dumps (Sharma and Roy, 2015):

Table IV

Prediction of shovel dump geometry

Shovel dump height (m)	Angle of overall slope (°)
60	35
70	33
80	32

i. Topsoil is dumped separately away from the existing internal overburden dump.

ii. To form a foundation for the dragline dump, no surface-soil may be dumped at the level from where coal has been extracted.

iii. By ensuring normal gravitational seepage of water in the direction of the sump area, nominal collection of water takes place where coal has been extracted.

iv. The dragline dump receives sufficient time to settle, followed by supplementary truck dumping, therefore the distance between the toe of shovel dump and the dragline dump is between 120 and 150 m, *i.e.* two cuts beyond the toe of the dragline dump (Sharma and Roy, 2015).

v. The voids in the dragline dumps are consolidated with the help of dozers.

vi. Some coal is left at the toe of the dump to act as a barrier (coal rib). It is designed in such a way that the overburden dump should cover up the coal rib/barrier as much as possible, and that the coal rib/barrier is likely to burn naturally.

vii. Efforts are made to extract coal from the coal rib without blasting, at regular intervals of 200 to 250 m along the strike length of the pit, so that there is no accumulation of water against the coal rib.

viii. Before dumping by dragline, the interface layer is cleaned from where coal has been extracted to as great an extent as possible (Singh *et al*., 2012). If possible, fragmented overburden rock is dumped to cover the slushy floor at the base of the dragline dump to increase the coefficleint of friction at the dump floor.

ix. As per the recommendations of BIT Mesra, Ranchi (Roy, 2016):

   a) If possible, the mine floor (foundation of internal dump) may be ripped or blasted at intervals to a depth of 1 to 2 m, thereby increasing the coefficient of friction prior to dumping by dragline (Government of India, 2019). It is also recommended that minor blasts to promote the flow of water to the sandstone beds below the open pit floor should be carried out to limiting water retention at the base of the dump.

   b) Regular monitoring of the dumps through a non-contact survey using a laser profiler or laser scanner is proposed to detect any movement of overburden dumps or dump faces that will indicate a potential dump failure. As the dragline dumps are inaccessible, a reflectorless instrument based on laser technology is recommended for surveying the displacement of the dump face between the crest and the toe of the dump.

c) It is proposed that monitoring of the dump should be carried out and recorded at seven-day intervals during the monsoon and post-monsoon seasons (July to November), whereas in the dry season (December to June) monitoring should be done at 15-day intervals. In the case of any movement of the overburden dump, the de-coaled floor near the toe of the dump is declared as a hazard zone with removal of men and machinery from the hazard zone.

d) The seepage of water from the face of the dragline dump is to be monitored when the coal rib has been breached at 7-day intervals from July to November and at 15-day intervals for rest of the period.

Conclusion

Based on the recommendation of the Birla Institute of Technology Mesra, the Jayant opencast project has maintained the dump profiles by adjusting the following parameters as shown in Figure 3-

a) Berm width at the coal rib roof level
b) Angle between the coal rib roof and the dragline mining level
c) Berm width at the dragline mining level
d) Slope angle above the dragline mining level.

The abovementioned measures have successfully prevented any major failure of backfilled dumps in spite of the huge volumes of waste rock (around 40 million m^3 per year loose volume) handled and dumped within the de-coaled area.

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