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Analysis of stress distribution on the bucket of a dragline machine

Overburden excavation is an integral component of the surface mine production chain. In large mines, the walking dragline is a trenchant and dominant mining machine. Due to the economic advantages, dragline is widely utilized machinery in the overburden excavation. These earthmovers carry out the earthmoving process with dragging, hoisting and dumping actions of the bucket. Dragline excavator's efficiency is critically important, since poor performance of a dragline in the mine site directly affects the total efficiency of ore production. The development of giant surface mining ventures in India like Bina and Jayant with setting up of higher coal production targets (up to 10 million tonnes per annum) calls for systems to remove large volume of overburden in shortest possible time. Therefore, productivity studies about dragline should be directed to decrease cycle time and increase payload, with avoiding catastrophic failure. In this regard, determination of stress distribution on the front-end components of dragline is meaningful to detect the external factors against dragline operation. In order to provide insight into the dragline bucket-formation interaction and stress distribution on the bucket, this paper provides an insight to the resistive force formation of horizontally moving dragline bucket where passive earth forces of the formation create resistance to the movement This paper denouement the background for analysis of resistive force against the bucket action of a walking dragline and also an analytic approach for cutting resisting model has been developed.

Keywords: *Dragline; resistive force; dragline bucket; cutting resistance*

I. Introduction

Opencast mining is one of the surface mining practices used for the extraction of layered coal reserves relatively near the surface. Overburden stripping is the essential activity in opencast mines to remove the overlying formation. Due to the economical advantages, draglines are predominantly utilized in this kind of mines for the removing of overburden, where the operation pit height is less than 35 m (Köse, 1987). A dragline achieves the earthmoving process using with the dragging, hoisting, and dumping actions of the bucket suspending from the boom.

Walking draglines are massive earthmoving machines which their weights typically range from 2000 to 7000 tonnes. They manage the stripping operations with penetrating, dragging, and hoisting actions of the bucket and carry the overburden with their booms with a length up to 128 m. The draglines generally work 24 hours a day, 364 days a year. The productivity of each dragline is generally estimated to be around $8000/hour and thus the cost of any unscheduled down time is very significant for the operation. Dragline-based stripping systems bring an economical saving up to 40 per cent, compared to shovel-truck method (Özdoðan, 1984). Fig.1 shows the relative changes of unit cost for different stripping ratios, economical advantage of dragline over shovel-truck system. Considering the production utility of draglines, 142 units of dragline whose bucket capacities are larger than 30 m^3 (40 yd3) are employed in 69 mines over the world (Gilewicz, 2000). These massive machines have a working capability of more than 10,000 service hours and most of them have a production capacity of 1 million tpy or more (Gilewicz, 2000). Prevalence of dragline utilization in opencast coal mining according to the countries is indicated in dragline performance depends on the operating speed, the bucket payload, and the machine availability, which could be negatively impacted by the actions taken to ameliorate the machine productivity.

During the execution of the dragline working procedure, working elements of dragline are exposed to sudden changes in stress and strain. These variations can cause fractures, wearings, and fatigue failures in the working parts of dragline. Especially, investigation of the interaction between formation and bucket tooth and determination of stress distribution on the bucket and its components during penetration and dragging processes are critical to estimate the diggability of dragline and the failure in bucket components.

II. Design

A dragline machine basically consists of two main sections as upper and lower constructions. Lower part contains

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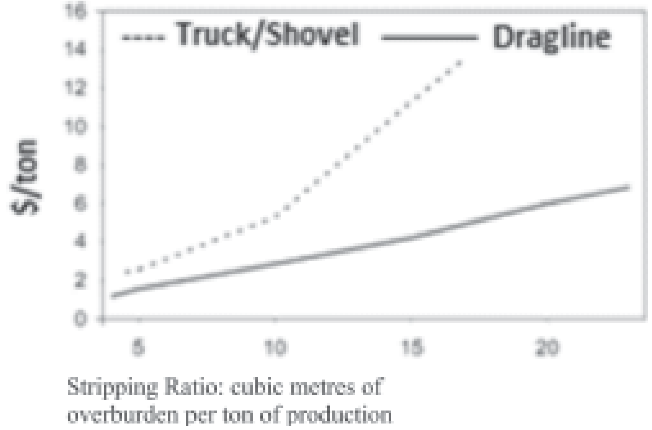


Fig.1 Economical comparison of shovel and dragline (Hartman, 2002)

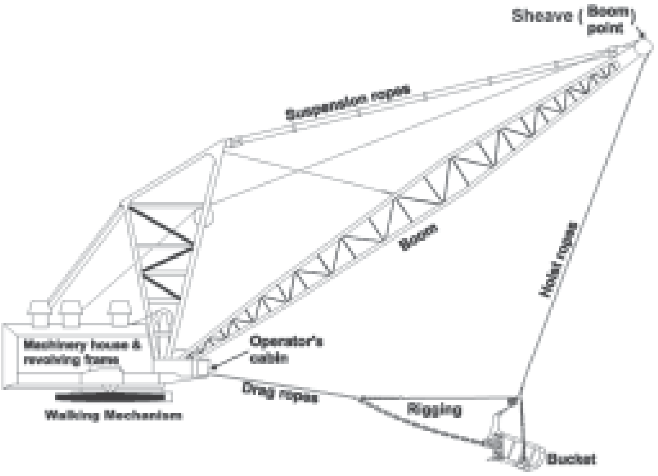


Fig.2 Schematic view of a dragline
(Modified after Gurgenci and Guan, 2001)

walking mechanism and metal chassis while upper part includes drives and operator cabins, excavation and haulage elements such as boom, bucket, chain, and metal rope (Tahir, 1985). Basic components of a dragline are shown in Fig.2. Performance of such an earthmover is controlled by the operator. Dragline operator provides the control of independent swing, hoist, and drag mechanisms to excavate and lift pre-blasted or soft rock from a pit, and dumping it onto an adjacent spoil pile (Ridley, 2004). During dragline activity, performance of the stripping is clearly affected by external factors. In general, these factors can be classified in two main categories, mine planning factors and operational factors (Demirel, 2009). Mine planning factors mainly deal with the subjects such as the selection of suitable dragline according to the excavation geometry and expected production amount, and blasting criteria of the site which determines the diggability of a dragline (Demirel, 2009). On the other hand, availability of dragline, fatigue life of working parts and maintenance programme, operator skill, cycle time, bucket load are the operational factors acting in dragline performance (Demirel, 2009).

III. Earthmoving action of a dragline bucket within the formation

An earthmover performs two main earth digging mechanisms such as cutting and penetration, according to their digging tool geometries and/or formation displacement abilities. When the shape of the digging tool is handled, a bucket mainly consists of two parts is as shown in Fig.3.

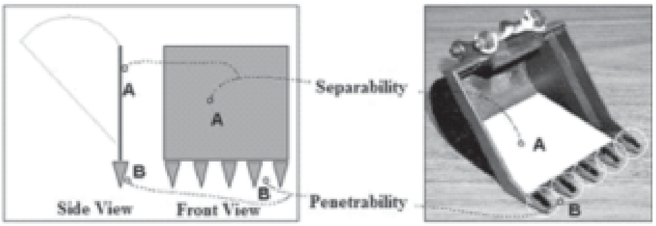


Fig.3 Penetration and separation parts of a bucket

Initially, a bucket has a rectangular shape floor component, named as the separation plate as stated with ‘A’ in Fig. 3. With the help of this plate, a bucket is able to move the formation by pushing or dragging (dragline bucket) it to the failure state. Secondly, the bucket has another mechanical component, teeth, as stated with ‘B’ in Fig.3. Bucket teeth penetrate the formation media to relieve digging mechanism. Dragline buckets are common overburden stripping tools used in the opencast mines. In a dragline, chain and rope combination gives axial motion to the bucket and determine the digging direction. The motional varieties provide the earthmover fully benefit from the separating and penetration ability of the bucket. Depending on the interaction conditions between bucket tips and the formation, the movements into the formation can be achieved into two different ways for the dragline, cutting, penetration. Fig.4 illustrates the kinds of earthmoving actions for a dragline bucket. As seen in Fig.4, the bucket firstly penetrates the formation with the help of its own weight and then, cut it along the operation direction. Fig.5 shows the orientation of a dragline bucket with the formation during the operation.

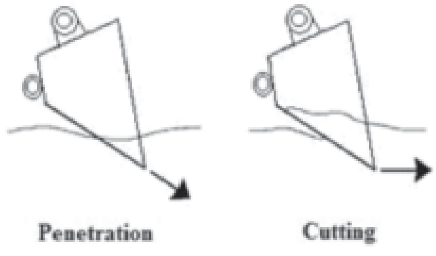


Fig.4 Fundamental earthmoving actions for shovel
(modified after Blouin, 2001)

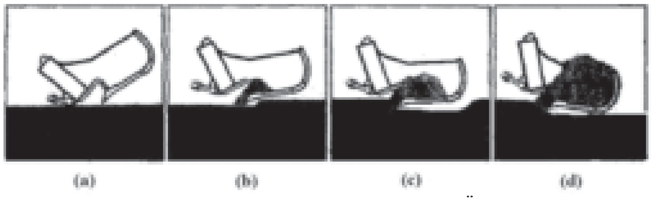


Fig.5 Dragline bucket earthmoving actions (Özdoðan, 2003)

IV. Background on the cutting resistance models

Interaction between cutting tool and formation can be described with the help of external and internal forces in the excavation area. One of the effective forces is the force exhibited by the formation against tool. To understand the condition better, it is required to discuss the types of lateral earth pressures back and front of the cutting tool. Weber (n.d) states that lateral earth pressures are divided into three categories, (i) active earth pressure, (ii) passive earth pressure, (iii) at rest earth pressure. At rest earth pressure appears on the plate when there is no lateral movement. On the other hand, active and passive earth pressures are effective when lateral displacement takes place. In Fig. 6, there is an illustration of active and passive force on the plate. When the plate moves away from the formation, environment for the active pressure evolves. With the displacement of plate, formation wall behind the plate is free to move outward and formation mass is activated under shear strength conditions. On the other side, passive earth pressure is initiated with the compression of formation in front of the moving plate. Lateral pressure continues to rise until the passive earth pressure is maximized.

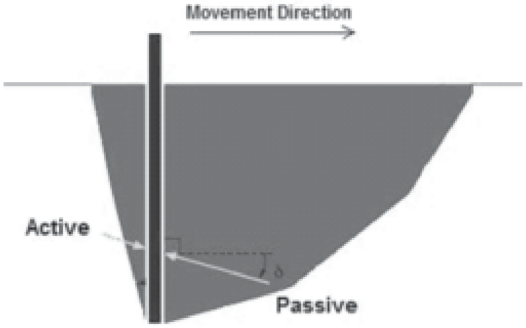


Fig.6 Active and passive pressure acting on the plate embedded in formation

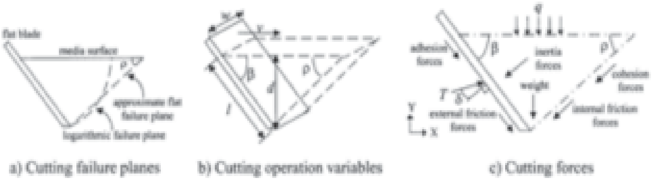
There are two common theories utilized to investigate the lateral earth pressures, Coulomb's and Rankine's theories (Craig, 1997). While the Rankine's theory mainly pays attention to plastic equilibrium and stresses in the formation body during the shear failure, the Coulomb's theory focus on the stability between the failure plain and an earth-retaining plane (Craig,1997). Application of Rankie's theory requires a failure environment with no adhesion and no friction between the plane and the formation. It is also limited to vertical walls. Coulomb's theory is also similar to Rankie's theory. However, formation-wall friction angle can be taken into the account only in the Coulomb's theory. Furthermore, wall subjected to lateral pressures do not have to be vertical in the theory. Most of the earthmoving theories use the basics of Coulomb's formation mechanics equations.

V. Analytical approaches for the cutting resistance models

Models used for the force estimation in earthmoving activities aim to find mathematical approaches for the counter force behaviour of formation on the moving tool. These models can be divided into 3 main categories according to the types of the earthmoving activities, penetration, cutting, and loading. Draglines perform the excavation operations with dragging, hoisting, and swing functions. It cuts the formation with its dragging function. Therefore, resistive force models for the cutting action are critical to estimate the stresses over the bucket.

In this perspective, Blouin et al (2001) presented a review study about the force prediction models for earthmoving tasks. In the review, it was emphasized that three-dimensional cutting models are apart from the two-dimensional cutting models with their side effect factors. However, Blouin et al (2001) also stated that there is negligible relationship between side effect findings of analytical three-dimensional models and those of a real bucket and Blouin et al (2001) also indicated that it can be utilized from two-dimensional models in force calculation of bucket digging process. Therefore, two-dimensional models will be analyzed and discussed under this title.

In the two-dimensional models, forces on the surface of the cutting plate are calculated in two-dimensional perspectives (Fig.7). For instance, Osman (cited in Blouin et al, 2001) utilized from the logarithmic approach to formulate two-dimensional cutting action. Both the behaviour of heavy medium without surcharge and cohesion and the behaviour of weightless medium with surcharge and cohesion were included in the model as equation components. The resultant cutting force is calculated as stated in Equation (1).



a) Cutting failure planes b) Cutting operation variables c) Cutting forces

Fig.7 Failure plane in formation cutting (Blouin et al., 2001)

$$\begin{aligned}T = {} & w[(0.5\gamma t^2\tan^2(45+0.5\rho)d_1+(e^{(2w\tan\rho)}\\ & -1/(4\tan\rho))r_o{}^2\gamma d_2+qt\tan^2(45+0.5\rho)d_4)d_3{}^{-1}\\ & +(0.5(r_1{}^2-r_0{}^2)c/\tan\rho+2c\tan(45+0.5\rho)d_4\\ & +qt/\sin(45-0.5\rho)\,d_5+C_a l d_7)\,d_6{}^{-1}\,] \qquad \text{... ... (1)}\end{aligned}$$

In Equation 1, T is resultant cutting force, γ is specific weight, w is tool width, d is tool depth, l is tool length, C is cohesion, C_a is adhesion, t is depth of Rankine Zone, ρ is shear plane angle, r_o is curvature radius, and d_1 to d_7 are graphical distances.

Projection of the resultant cutting force on the horizontal plane is in Equation (2).

$$H = T\sin(\beta+\delta) \qquad \text{... ... (2)}$$

In Equation 2, H is horizontal force, β is rake (cutting) angle, and δ is external friction angle.

VI. Cutting resistance model applications

Formation cutting involves the mechanical failure of formation, which usually occurs in the shear mode along internal rupture surfaces in the formation, and often at the boundary between the cutting tool surface and the formation (McKyes, 1985). In the modelling of tool-formation environment, methods like finite and discrete element solutions, geometric simulation and the passive earth theory are applicable to estimate interactions forces (Offei and Frimpong, 2009). In concern with the passive earth theory, Ericsson (2000) simulated the excavation of wheel loader in software. The author divided the resistive forces of formation against the bucket as cutting, penetration, inertial forces and mass flow, and utilized from MyKyes's method to calculate approximate counter force in the formation during the cutting operation.

Besides the theoretical models, some laboratory studies have been executed to optimize the bucket cutting. Maciejewski and Jarzebowski (2002) carried out the digging process of bucket in a laboratory stand. They basically performed the operation with a cutting tool into the formation, mounted on the hydraulic cylinders which measure the horizontal, vertical, and rotational forces during the process. With theoretical predictions and experimental observations, they modified the parameters such as shape of cutting tool, digging trajectory, and the angles of tool-formation interaction angle. Specific energy measurements in the cylinders were taken as indicator for the effect of parametric changes on overall digging efficiency.

VII. Conclusions

The analysis indicated that stress amounts on the elements were mostly effected by the change in internal friction angle and least affected by the change in density. Detailed stress analysis on the dragline bucket shows that:

1. Sharp edges on the front of bucket are closest to fail during the operation. These edges are required to be rounded and strengthened by welding or any other metallurgical method.
2. Internal friction is most significant formation factor to determine the resistive forces on the bucket. On the other hand, density is least effective to change the pressure values on the bucket parts.
3. Material selections for the solid bodies greatly influence the mechanical behaviour of the parts under loading conditions.

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DEVELOPMENT OF A HANDY METHODOLOGY FOR THE SELECTION OF SURFACE MINER IN VARIED ROCK MASS CONDITIONS FOR MASS PRODUCTION OF COAL AND LIMESTONE

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