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Particle flow mechanism into cable shovel dippers

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Abstract

Electric cable (or rope) shovels are critical equipment in the surface mining industry. An improved understanding of the factors which affect the flow of broken material into the dipper during loading can help to evaluate the performance of the excavator, define the criteria for equipment selection and develop ways to mitigate equipment damage caused by broken particles. In this paper, the mechanism of granular material flow was investigated through a series of laboratory tests by moving 1:32 and 1:20 (cube root scale) models of a 44 m^3 dipper through a test bin filled with angular crushed limestone. It was found that neither dipper angle nor hoist speed has significant influence on the general flow pattern. It was also found that the general flow mechanism is independent on the size of the dipper. Quantitatively, it was determined that hoist speed and pitch angle affect the productivity of the machine with lower pitch angle resulting in higher payload, and faster hoist speed results in shorter dig time. While both lower pitch angle and faster hoist speeds also produce a higher rate of energy consumption, overall both contribute to improved machine productivity.

Keywords: Particle flow; Cable shovel; Ground engaging tools; Dipper; Hoist speed

1. Introduction

Electric cable (or rope) shovels are critical equipment in the surface mining industry. Several parameters influence the productivity and efficiency of such excavators, including material properties. Material properties such as particle size, shape, size distribution, stiffness, and density affect the dig performance of electrical cable shovels (Singh et al., 1992).

The interaction between ground engaging tools and their working media has been studied extensively. The previous works may generally be divided into analytical, experimental and numerical modelling approaches. In general analytical models are structured around classical soil mechanics including the deformation and failure of soils (Terzaghi, 1943; Osman, 1964; Reece, 1965; Heitiaratchi et al., 1966; Hemami et al., 1994). Analytical models depend little on a specific type of material that is one of the benefits of these methods. But, the applicability of such models is limited to simple ground-equipment (tool) interaction scenarios, such as the cutting action with a wide blade (Frimpong and Hu, 2004). Complex tool geometry such as shovel dipper, and large deformations cannot be modelled using these methods (Coetzee and Els, 2009). Within the category of experimental approaches, most studies investigated the influence of particle size and the size distribution of blasted material (Singh et al., 1992; Singh and Narendrula, 2006; Hendrics et al., 1990; Karpuz et al., 1992; Taksuk and Erarslan, 2000), with a few studying the effect of fragment shape (Hendrics et al., 1988; Singh and Narendrula, 2006).

Particle flow occurs in a broad spectrum of mining approaches, an example of which would be digging in a

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blasted rockpile using ground engaging tools such as a shovel dipper. Joseph and Shi (2012) noted that excavating depends on material properties such as particle size, shape, and size distribution, and the dipper rake angle that encourages the material into the dipper (Joseph and Shi, 2012). Rowlands (1991) developed the "Shear Zone Theory" which described the flow characteristics of material loading into a dragline dipper (Rowlands, 1991). In addition, Rowlands (1991), Rowlands and Just (1992) experimentally investigated the filling behaviour of a scale model dragline dipper to study the effect of dipper shape, rigging conjunctions, and tooth spacing; Rowland also showed that bucket aspect ratio (width to depth) is an important parameter in digging efficiency (Rowlands, 1991; Rowlands and Just, 1992). Experimentally the process of filling an excavator dipper was investigated by Maciejewski et al.; the aim of their research was to determine the effect of teeth (number and position) on a dipper lip on dig efficiency. This research found that in the case of excavation using ultra class shovels a plane strain condition may be happens generally, or locally based on the number and spacing of the teeth (Maciejewski and Jarzebowski, 2002; Maciejewski et al., 2004).

In addition to experimental and theoretical studies, numerical modelling and discrete element methods (DEM) have been widely used to predict the behaviour of granular material. For example, Coetzee et al. proposed a way to estimate the input parameters for modeling cohesion-less materials flowing into a dragline dipper using DEM and found a good agreement between the observed and the modelled flow regions in terms of position and transition from one stage to the other (Coetzee et al., 2007, 2010; Coetzee and Els, 2009). Cleary also modelled dragline dipper filling using DEM and evaluated the effect of particle shape on the performance of the dragline dipper; however, one weakness of these studies was that no experimental verification was provided to support the numerical results (Cleary, 1998, 2000, 2004, 2009).

Although the filling behaviour of a dragline dipper has been studied experimentally or through discrete element modelling simulations, no cable shovel dipper filling investigation was identified. Since an improved understanding of dipper–ground interaction leads to the improved efficiency and productivity of heavy-duty excavators, this study has focused on the development of a flow mechanisms for broken rock into cable shovel dippers.

1.1. Cable shovel operation

The main parts of a cable (rope) shovel are the lower works, the upper structure, and the attachment which comprises the boom, the dipper, the crowd, and the dipper handle (Fig. 1). The principle motions of a cable shovel may be classified as; hoist and crowd related to the dig cycle, and swinging and propelling related solely to the movement of the machine. The hoist and crowd motors generate the hoist and crowd motions. The hoist motion is achieved via a rope drum lifting the dipper, while the crowd motion is accomplished by a rack and pinion arrangement between the crowd arm and the boom, respectively. During the crowd motion, the handle is extended out and the dipper moves towards the active face. Effectively lengthening the handle and raising the hoist rope generate a dig cycle trajectory describing the dig kinematic (Stavropoulou et al., 2013).

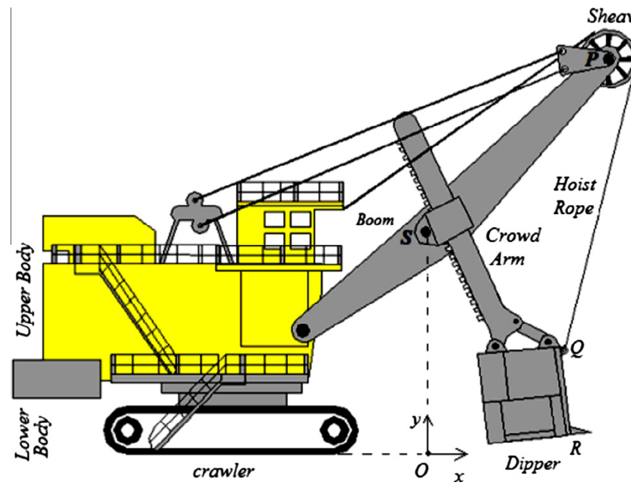

Fig. 1. Cable shovel nomenclature (Stavropoulou et al., 2013).

Fig. 2 shows the components of a typical shovel dipper (Shi, 2007). The dipper tooth and rake angles are two of the main factors in determining the filling factor as an expression of the efficiency of a dipper, plus the required power to complete a dig cycle. An imaginary line connecting the dipper lip to the rack pinion contact-with the dipper handle, describes the rake angle as an angle made with a horizontal line (Fig. 3) MinePro, 2001. Rake angle is controlled by the length of pitch braces. The tooth angle is further adjusted based on the rake angle setup. In general, it is desirable to have the largest possible tooth angle to maximize the cutting action; together with proportionally minimal wear, resulting from a moderate heel band clearance. A steeper rake angle is more effective in easier digging conditions with less wear. However, where the wear is severe, under heavier digging conditions, a smaller rake angle would be potentially more desirable (MinePro, 2001).

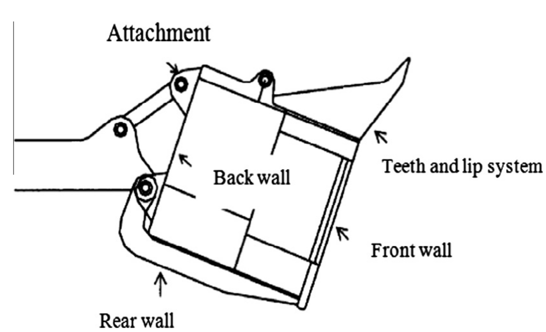

Fig. 2. 2D illustration of typical cable shovel dipper (Shi, 2007).