Influence of rake angle, bucket width and teeth depth of dragline bucket on the resistive force in different rock types

Draglines are used to dispose the overburden for exposing minerals in a surface mine. Draglines may be greater than 4000 t in overall weight, with bucket capacity ranging from 24 to 120 m^3. The buckets are dragged against the blasted muck to fill the blasted overburden materials[1]. Bucket teeth fail easily while the excavator is being operated due to the fact that they are in direct touch with the rocks. The bucket teeth have an appropriate geometrical design for longer life and cost reduction[2].

Different bucket designs are in use to enhance the productivity and removal of blasted materials. The shape of the bucket teeth is an important parameter which is responsible for the resistive force. More optimized the shape of the bucket teeth, lesser is the resistive force. In the digging process, a host of different rock conditions are faced by the bucket teeth[3]. The repairing of dragline bucket teeth in site.

Bucket teeth being in direct interaction with the rocks, experience maximum stress condition in the bucket chain assembly[3]. Researchers have compared three bucket designs, their angles and shape[4]. There are certain factors affecting bucket penetration like bucket penetration angle, bucket weight, bucket teeth and excavation bench slope angle[5]. Penetration of the bucket, i.e. depth of cut, is governed by rake and tooth angles of the bucket[6].

The fundamental earthmoving equation predicts soil-resistive force that is contrary to the blade (bucket tooth) that moves to the ground horizontally. The essential earthmoving equation predicts the static pressure which is required to cut the rock primarily based on all the forces on the wedge[7].

In this study, the McKyes's 2D model as given in eq. (1) has been used and the forces due to cohesion, weight, adhesion, inertia and overloading have been evaluated to express the resistance of a formation to earthmoving[8]

$$P = w(\gamma g d^2 N_\gamma + c d N_c + C_a d N_{ca} + q d N_q + \gamma v^2 d N_a), \quad (1)$$

where P is the cutting force (N), w the bucket width (m), γ the overburden material density (kg/m^3), g the gravitational acceleration (m/s^2), d the teeth depth (m), c the cohesion (Pa), C_a the adhesion (Pa), q the overload (N/m^2), v the formation cutting velocity (m/s), N_c the cohesion coefficient, N_γ the weight coefficient, N_a the inertia coefficient, N_{ca} the adhesion coefficient and N_q is the overload coefficient.

From eq. (1), the total resistive force on the teeth can be estimated from forces related to the weight of removing broken rock material, cohesion in the broken rock material, adhesion between tool and rock, surface surcharge pressure and inertia inside the broken rock (Figure 2). In this study, resistive forces such as adhesion, surcharge and inertia forces have been neglected in the calculation of total resistive force[8]. The overload pressure due to additional load on the formation surface, leading to increased compaction of the formation, has also been neglected. Moreover, the adhesion force can be described as the force of attraction between different materials. In this study, rock and bucket teeth are two distinct materials and interaction between them is assumed to be zero[8]. Also, the impact of inertia has been observed when the formation is elevated from a resting state at a selected speed[9]. Since constant speed bucket movement was applied in the study, the inertial force was also neglected. Figure 2 illustrates the resistive force model[10].

In Figure 2, α, δ, β, ϕ are rake angle, external friction angle, shear plane angle, internal friction angle respectively. Rake angle plays a critical role in the design of the teeth. For the optimum value of rake angle, material flow along the teeth will be smooth. At the same time, specific pressure acting on the teeth will have a lesser value, which increases the tool life.

In this study, for determination of resistive forces two factors, viz. weight and cohesion have been considered.

According to the model assumption of the cutting force eq. (1) can be rearranged in the form of eq. (2) below[8]

Figure 1. Dragline bucket teeth repair on site.

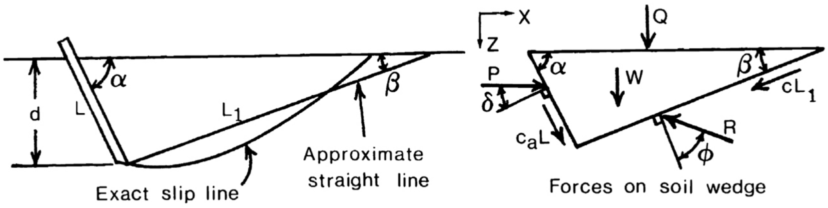

Figure 2. Resistive force model.

$$P = (\gamma g d^2 N_\gamma + c d N_c) w, \tag{2}$$

$$N_y = \frac{\cot\alpha + \cot\beta}{2[\cos(\alpha+\delta) + \sin(\alpha+\delta)\cot(\beta+\varphi)]}, \tag{3}$$

$$N_c = \frac{[1 + \cot\beta\cot(\beta+\varphi)]}{[\cos(\alpha+\delta) + \sin(\alpha+\delta)\cot(\beta+\varphi)]}, \tag{4}$$

put the values of N_y and N_c in eq. (2), we get

$$P = \frac{w[\{\gamma g d^2(\cot\alpha + \cot\beta)\}}{2\{\cos(\alpha+\delta) + \sin(\alpha+\delta)\cot(\beta+\varphi)\}} + \frac{cd\{1 + \cot\beta\cot(\beta+\varphi)\}]}{\{\cos(\alpha+\delta) + \sin(\alpha+\delta)\cot(\beta+\varphi)\}}. \tag{5}$$

Equation (5) is a fitness function equation which is used in MATLAB to minimize the function and optimize the rake angle.

In the present study, two types of broken rock material encountered by the dragline during excavation have been analysed in a surface mine, namely sandstone rock and shale rock. Table 1 shows the properties of these rock materials[11,12].

In the present study, certain parameters were assumed to be fixed while others were changed to study the impact of these variable parameters on the

Table 1. Material properties[11,12]

Material	Properties
Sandstone	Density: 2000 kg/m^3 Cohesion strength: 25,000 Pa Internal friction angle: 30°
Shale	Density: 2500 kg/m^3 Cohesion strength: 30,000 Pa Internal friction angle: 27°

Table 2. Input parameters

Fixed parameters	Variable parameters
d = 0.512 m w = 4.0 m	Rake angle α = 15° to 90° Shear plane angle β = 14° to 32°
c = 25,000 Pa	External friction angle δ = 20° to 30°
g = 9.81 m/s^2 γ=2000 kg/m^3 Internal friction angle φ = 30° for sandstone and 27° for shale	

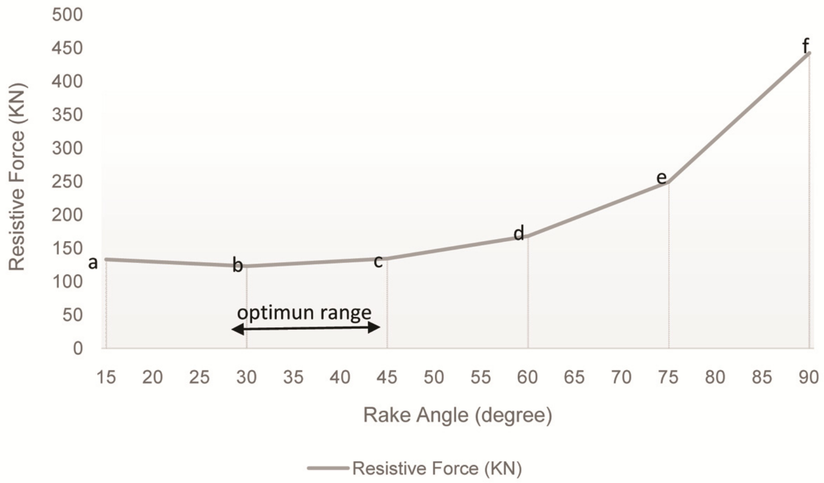

Figure 3. Effect of rake angle on resistive force for sandstone rock.

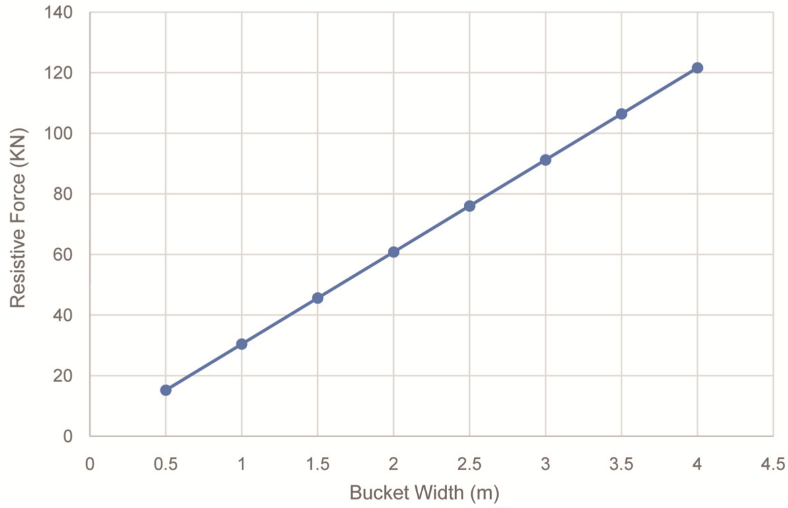

Figure 4. Plot of bucket width versus resistive force.

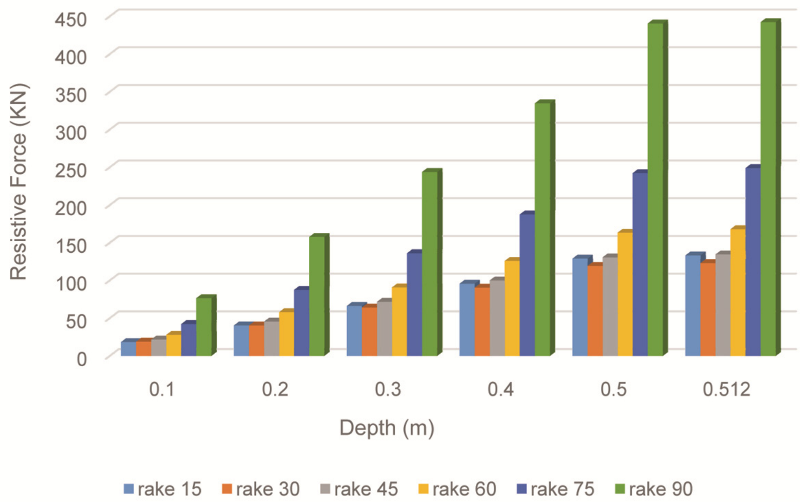

Figure 5. Effect of teeth depth on resistive force.

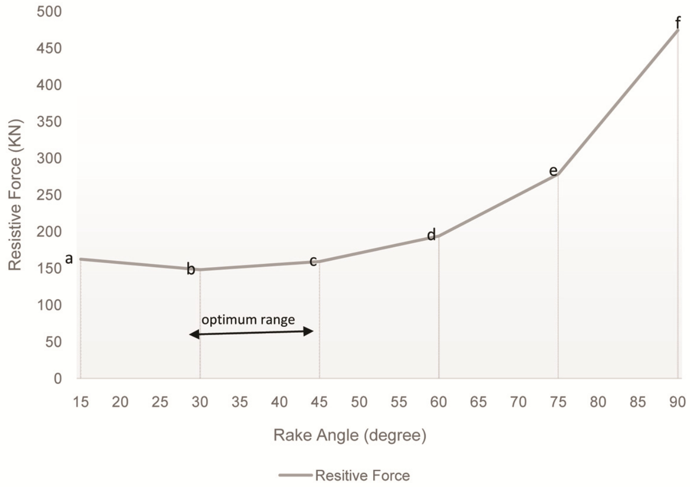

Figure 6. Effect of rake angle on resistive force for shale rock.

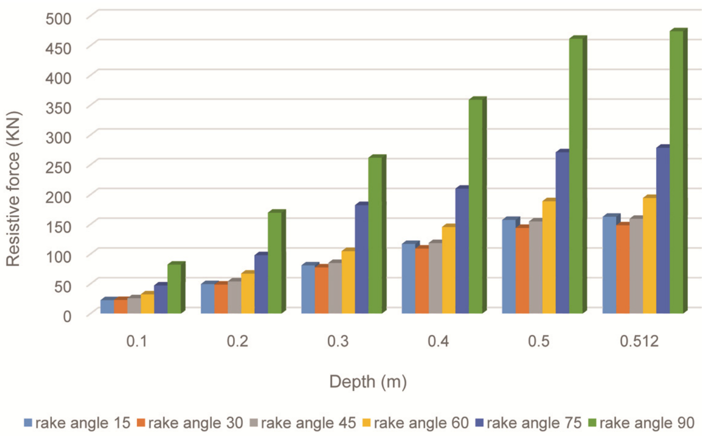

Figure 7. Effect of teeth depth on resistive force.

performance of dragline buckets. Input parameters are shown in Table 2.

In the case of sandstone rock, the rake angle of bucket teeth was varied from 15° to 90° to evaluate the resistive force.

As shown in Figure 3, the optimum range of the rake angle was found to be 30°–45°. When the rake angle of the bucket increases from 30° to 60°, the resistive force gradually increases. On further increasing the rake angle from 60° to 75°, the resistive force suddenly increases. When the rake angle increases from 75° to 90°, the resistive force increases sharply. So, for smooth working of the dragline bucket, the rake angle should lie between 30° and 45°.

In this study, the maximum value of dragline bucket width has been taken as 4 m, and the maximum value of teeth depth as 0.50 m.

As shown in Figure 4, when the bucket width increases, the resistive force also increases. From Figure 5, it is clear that when teeth depth increases, the resistive force also increases for a given rake angle value.

Similar studies were conducted for shale formation. It is evident from Figure 6 that the optimum range of rake angle is 30°–45°. When rake angle of the bucket increases from 30° to 60°, the resistive force gradually increases. On further increasing the rake angle from 60° to 75°, the resistive force suddenly increases. When the rake angle increases from 75° to 90° resistive force increases sharply. So, for smooth working of the dragline bucket, the rake angle should lie between 30° and 45°.

Figure 7 is a plot between resistive force and bucket teeth depth. It is clear that as the bucket teeth depth increases for a particular value of rake angle, the resistive force also increases.

The present study was carried out to evaluate the effect of parameters such as rake angle, bucket width and teeth depth on resistive force. The resistive force was found to increase with increase in rake angle, bucket width and teeth depth; so it is necessary to select the optimum value of rake angle. From the analysis, the optimum range of rake angle was found to be 30°–45° both for sandstone and shale rock.

1. Azam, S. F. and Rai, P., *ASME J.*, 2018, **78**, 392–402.
2. Cristine, H. and Tasevski, A., *Design of Bucket Teeth*, Master thesis, Academy of Innovation, Design and Engineering, Malardalen University, Sweden, 2016.
3. Khedkar, Y., Dey, T. and Padasalagi, Y., *J. Appl. Mech. Eng.*, 2017, **6**(5); doi: 10.4172/2168-9873.1000282.
4. Lomate, S., Biradar, S., Dhumal, K. and Waychal, A., *Int. Res. J. Eng. Tech.*, 2016, **3**(8), 1423–1429.
5. Ozdogan, M., Bucket penetration mechanism and bucket penetration forces of walking draglines, 2015; doi:10.13140/RG.2.1.2304.8406.
6. Ozdogan, M. and Qzdoganb, H., Digging forces of electric rope shovel and adjustments made for a better digging shovel having optimum dipper rake and tooth angles. In International Black Sea Mining and Tunneling Symposium, Trabzon, Turkey, 2–4 November 2016.
7. Suryo, S. H., Bayuseno, A. P., Jamari, J. and Wahyudi, A. I., *Civ. Eng. J.*, 2018, **3**(12), 1222–1234.
8. Golbasi, O. and Demirel, N., *J. S. Afr. Inst. Min. Metall.*, 2015, **115**(7), 623–628.
9. Abo-Elnor, M., Hamilton, R. and Boyle, J. T., *Soil Tillage Res.*, 2004, **75**(1), 61–73.
10. McKyes, E. (ed.), *Soil Cutting and Tillage*, Elsevier, Amsterdam, 1985, p. 7.
11. Strength, R., MChapter 14. *Landslides. Investigation and Mitigation*, 1996, **1586**, 372.
12. Zhu, T. Y., Some useful numbers on the engineering properties of materials (geologic and otherwise). GEOL 615, Department of Geophysics, 2012.

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SHAH FATEH AZAM*
PIYUSH RAI

Indian Institute of Technology,
Banaras Hindu University,
Varanasi 221 005, India
**For correspondence.*
e-mail: Shahfateh.azam29@gmail.com