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Performance prediction of impact hammer using ensemble machine learning techniques

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ABSTRACT

Various mechanical excavation systems such as roadheaders, tunnel boring machines (TBM), and impact hammers, are commonly used in mining, tunneling, and civil engineering projects. However, in recent years, the application of impact hammers in hard rock excavation has been on the rise, especially in fractured geological formations. Impact hammers offer some advantages over drill and blast systems like selective mining, mobility, less over excavation, minimal ground disturbance, elimination of blast vibration, reduced ventilation requirements, and compared to TBMs, low specific energy and small initial investment cost.

Prediction of the net machine production rate in terms of net (instant) breaking rate (NBR) plays an important role in estimation of completion time, schedule and cost of the projects. Performance prediction models has been developed based on field data where Impact hammers were used in tunneling operations. While some models are based on statistical analysis of field data, a fewer subset have been developed using artificial neural network (ANN). In this study, 121 data sets, including machine production rate, uniaxial compressive strength (UCS), rock quality designation (RQD), excavator power (P), and weight of excavator (W) have been compiled and using a CRISP-DM data mining technique along with principal component analysis (PCA), a new model for prediction of the impact hammer performance has been introduced with R^2 of over 85%.

1. Introduction

The tunneling industry has witnessed much of advances in past few decades and tunnel boring machines (TBM) have become the dominant method of tunneling in many operations. However, the use of rock TBMs is uncommon in short tunnels and even when TBMs are to be used, there is a need to excavate starter and tail tunnels to assemble and start the TBMs, Currently, in such cases drill and blast method is used, however, D&B method is not the preferred option in urban areas, and in some cases they are strictly prohibited. In favorable conditions, roadheader and impact hammer are preferred due to many advantages they offer over conventional methods. These include improved safety, minimal ground disturbances, elimination of blast vibration, reduced ventilation requirements, and low cost (Ocak and Bilgin, 2010). When compared to roadheaders, impact hammers can offer comparable or superior performance in jointed rock mass that is stronger and more abrasive. In such conditions, bit consumption for roadheaders will be very high and will drive the machine utilization rate down, which increases the excavation related costs.

Impact hammers have been widely used in mining, and civil engineering projects around the world, both in surface and in underground operations. In recent years, the application of impact hammers in hard rock, especially in fractured geological formations, has been on the rise. Selection of mechanical excavators or drill and blast should consider factors such as advance rates, costs, set up time, feasibility, and the ability to negotiate adverse geological conditions (Terezopoulos, 1987). Impact hammers can be mounted on different types of excavators (i.e. a backhoe chassis as carrier), and break the rock mainly by impact forces applied by a piston or hammer hitting an adapter at high speeds (Iphar, 2012). Fig. 1 shows an example of impact hammer mounted on excavator.

Impact hammers or hydraulic breakers convert oil flow into the linear and reciprocating motion of a ram that impacts against a replaceable steel rod. A hydraulic breaker is designed to be mounted in place of a digging bucket on construction equipment such as track or wheel excavators, backhoe loaders and skid-steer loaders. The breaker is connected the hydraulic system of the host carrier to receive the input pressure required for operation. The steel rod, whose tip may be a

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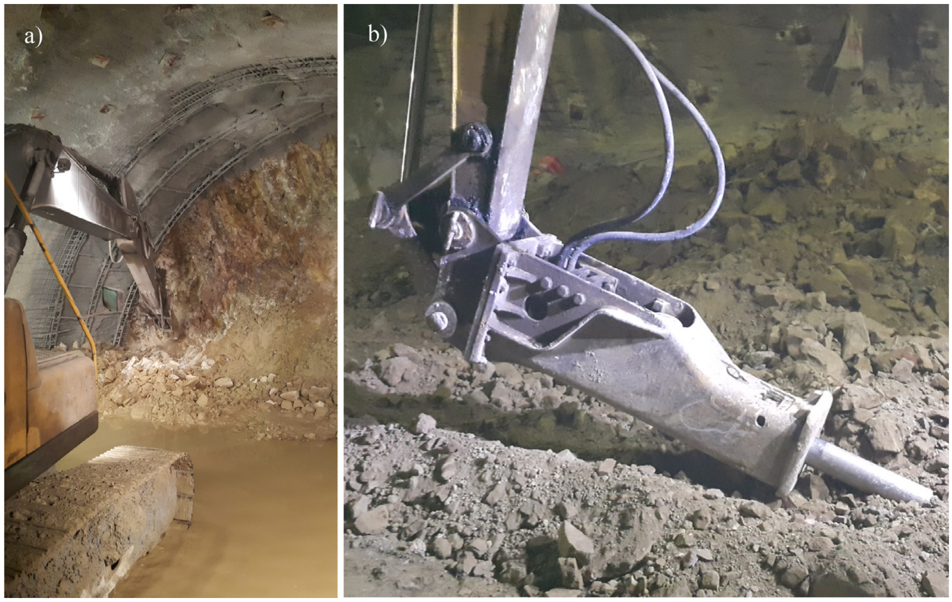

Fig. 1. (a) A tunnel excavation with impact hammer mounted on excavator, (b) view of this impact hammer.

chisel, moil or blunt tip, delivers percussive force to the material to be broken. Common uses for hydraulic breakers include breaking oversize boulders on ore-pass grizzlies and scaling, to remove loose material from rock faces. Hydraulic breakers are also used for breaking concrete, brick and asphalt (SME, 2011).

Factors affecting the excavation performance of tunneling machines can be briefly summarized as: (i) intact rock properties (UCS, tensile strength, hardness, abrasiveness, elasticity, plasticity, brittleness), (ii) rock mass properties (bedding planes, joints, fractures, fault zones), (iii) machine parameters (available power, machine weight, thrust and torque), (iv) cutting mode employed (sumping, traversing, undercutting, overcutting), (v) cutting tools (drag bits, roller cutters), (vi) cutting geometry (spacing of the cutters, cutting depth, rake angle, angle of attack), (vii) operational factors (gradient, water inflow, haulage capacity, support requirements), (viii) size and shape of the opening, and (ix) operator skills (Iphar, 2012).

However, it should be noted that the overall efficiency depends not only to the factors explained above, but also on how well the hammer sits on the rock at the time of hammering. It is also important to consider that the longer the boom is, the heavier the excavator should be. Fig. 2 illustrates the weight balance of an excavator and impact hammers. The magnitude of reflecting force that shakes the excavator boom depends also on the structure of shock absorbers between the hammer and the excavator boom (Tuncdemir, 2008).

Balance of moment forces between excavator and hammer weights are given in Eq. (1). The ratio given in Eq. (1) is called balance ratio. Where A is maximum reach of carrier; B is half length of wheel base; Wh is weight of hammer; and Wc is weight of carrier (Wyllie, 1985).

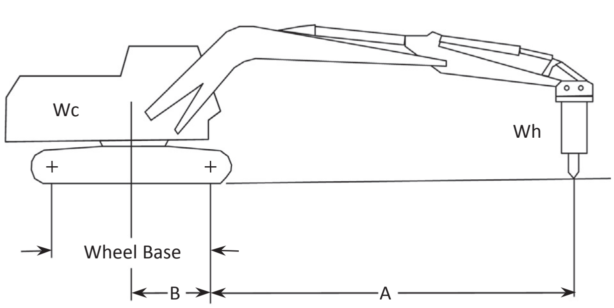

Fig. 2. The weight balance of an excavator and hydraulic hammer (Tuncdemir, 2008).

$$0.30 < \frac{A\times Wh}{B\times Wc} < 0.50 \tag{1}$$

Prediction of the machine performance plays an important role in estimation of the time of completion, project scheduling, and cost. Field data can be used as a basis for development of performance prediction models (Ocak and Bilgin, 2010), in terms of the net (instant) breaking rate (NBR) of an impact hammer. NBR is defined as the production rate during excavation in m^3/h and is controlled by several parameters such as rock properties, ground conditions, machine specifications, and operational conditions. Some impact hammer performance prediction models have been published in the literature using a combination of these parameters. However, these models generally have weak or moderate correlation with the actual field performance of impact hammers. In general, there are two methods for prediction of NBR. The first method is based on the empirical models developed based on statistical analysis of field data, and the second method is based on using various artificial intelligent methods.

Studies on the performance prediction of impact hammers goes back to the publications by Evans (1974), Grantmyre and Hawkes (1975), Mahyera et al. (1982) and Afrouz and Hassani (1987) (Tuncdemir, 2008). Evans (1974) points out that the susceptibility of the rock to impact breakage is a function, not only of compressive strength but tensile strength as well. A review of research on the mechanics of rock breakage by impact hammers and the role of high-energy impact is discussed by Grantmyre and Hawkes (1975). Mahyera et al. (1982) offer an empirical model for estimation of the breaking capabilities of hydraulic hammers based on laboratory testing of small rock samples. The results were also compared with data collected in field applications. An empirical approach for the analysis of rock breakage under direct impact in laboratory conditions is offered by Afrouz and Hassani (1987), where the characteristics and mechanism of fragmentation in the test blocks were discussed. Bilgin showed that Schmidt hammer rebound value is a good indicator of rock characteristics and shows significant correlation with net breaking rates of impact hammers when the rock formation is grouped based on RQD values (Bilgin et al., 2002).

Bilgin also developed a model based on data collected from different tunneling projects in Istanbul as presented below (Bilgin et al., 1996, 1997, 2002):

$$\mathrm{NBR} = 4.24P_i(\mathrm{RMCI})^{-0.567} \tag{2}$$