Engineering Geology 173 (2014) 1–9

Contents lists available at ScienceDirect

Engineering Geology

journal homepage: www.elsevier.com/locate/enggeo

Penetration rate prediction for diamond bit drilling by adaptive neuro-fuzzy inference system and multiple regressions

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ARTICLE INFO

Article history:
Received 4 July 2013
Received in revised form 13 February 2014
Accepted 15 February 2014
Available online 20 February 2014

Keywords:
Diamond bit drilling
Penetration rate
Multiple regression modeling
Adaptive Neuro-fuzzy Inference System
Modeling

ABSTRACT

In many mining, civil, and petroleum engineering applications diamond bit drilling is widely used due to high penetration rate, core recovery and its ability to drill with less deviation. Recently, many research have been conducted to estimate the penetration rate of diamond drilling which can be considered as one of the most important parameters in project planning and cost estimation of the operation.

A database covering the rock properties and the machine operational parameters collected from seven different drilling sites in Turkey is constructed. Construction of an adaptive neuro-fuzzy inference system and the multiple regression models for predicting the penetration rate of diamond drilling is described. In the models, rock properties such as the uniaxial compressive strength, the rock quality designation, and the equipment operational parameters like bit load and bit rotation are considered. Although the prediction performance of multiple regression models is high, the adaptive neuro-fuzzy inference model exhibits better performance based on the comparison of performance indicators. By using the models, penetration rate of diamond bit drilling can be predicted effectively.

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1. Introduction

Although drilling is an expensive operation, it is still widely used in different engineering applications, since it is the most reliable and the safest way for the identification and exploration of the deep natural resources.

Diamond drilling is the most widely used drilling method in many mining, civil, and petroleum engineering practices due to its higher penetration rate, core recovery, low deviation and greater precision. The role of diamond drilling can be different depending on the purpose of engineering practice. In mining engineering, diamond drilling is dominantly used for mineral exploration and gathering geotechnical information. Civil engineers use diamond drilling for construction purposes and gathering geotechnical information. In petroleum engineering diamond drilling is used for oil and gas exploration.

Proper and optimum drilling performance leads to reduced costs in the overall project body (Lummus, 1970; Estes, 1973; Singh et al., 2009). Drilling performance is optimized with increase in the penetration rate while decreasing the bit wear.

Many researchers tried to establish a link between penetration rate of diamond drill and rock properties. Paone and Madson (1966) carried out a laboratory test program for correlating the penetration rate with rock properties, and reported that penetration rate well correlated with the uniaxial compressive and tensile strength of the rock. Howarth et al. (1986) found strong correlation between the penetration rate and rock properties such as dry and saturated density, saturated P-wave velocity, saturated uniaxial compressive strength and apparent porosity. Kahraman (2002) reported that there was a strong correlation between penetration rate and brittleness values obtained from uniaxial compressive strength and tensile strength. Kumar et al. (2011, 2013) made an attempt to estimate rock properties such as uniaxial compressive strength, Schmidt rebound number and Young's modulus using sound level produced during rotary drilling.

Some researchers considered the operational parameters of the drilling equipment in addition to the rock material properties for estimating the penetration rate. Karpuz et al. (1990) developed a curvilinear model for predicting penetration rate using information obtained from drill holes at 96 different locations. They concluded that uniaxial compressive strength was the dominant rock property. Paone et al. (1969a) reported that thrust, rotational speed, uniaxial compressive strength, shore hardness and quartz content were the significant properties affecting penetration rate. The results of the analyses conducted by Ersoy and Waller (1995) showed that weight on the bit, rotational speed, Cerchar abrasivity index and shore hardness were the significant parameters affecting the penetration rate. Akun and Karpuz (2005) performed statistical analyses using drilling data for sandstone. They used RQD, discontinuity frequency, pressure loss, specific depth of cut and specific energy to predict penetration rate.

Estimation of penetration rate is a complex task, since it depends on many factors such as rock material and rock mass properties as well as drilling equipment operational parameters. For such kinds of complex

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http://dx.doi.org/10.1016/j.enggeo.2014.02.006
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problems, recently soft computing methods like neural network and fuzzy modeling have been employed by researchers (Akın and Karpuz, 2008; Arabjamalaloei and Dehkordi, 2012). It is suggested that soft computing methods can successfully be applied for estimation of penetration rate, and they exhibit better performance than traditional regression modeling.

In this article adaptive neuro-fuzzy inference system (ANFIS), a hybrid modeling method combining fuzzy logic and neural network, is used to estimate the penetration rate using rock material, rock mass and drilling equipment operational parameters. Results obtained are compared with those of the traditional multiple regression modeling.

2. Field and laboratory studies

Input data for this work cover seven boreholes drilled at six different regions around four cities of Turkey (Akun, 1997). All of the drilling activities were carried out by the Mineral Research and Exploration Institute of Turkey (MTA).

Exploration drilling activities were conducted at Kilimli, Bartin, and Kandilli regions around the city of Zonguldak hard coal basin. Other drilling activities were around cities of Izmir, Manisa and Ankara at regions of Kinik, Maldan and Dodurga, respectively. Location of the cities and the regions where drilling activities were conducted are shown in Fig. 1.

Zonguldak hard Coal Basin is a formation of the Late Paleozoic–Mesozoic age, involving various faults and topographic irregularities along the North Anatolian Mountain Range. The Carboniferous clastic sequence of Zonguldak basin contains several coal seams that have been mined since 1848 by underground methods. Coal seams are located in a Namurian to Westphalian D progradational delta and fluid plain sequence that is approximately 3500 m thick (Karacan and Okandan, 2000). Detailed geological description of the region can be found in Alan and Aksay (2002) and Can et al. (2012).

Around Kinik region of Izmir city, the Neocene sequence is dominantly observed. Sequence consists of a fluviatile basal conglomerate unit, the lacustrine Küçükderbent Formation and the volcanic rocks of the Sidan Formation. More detailed information about the geology of the regions around Izmir city is given by Unay and Goktas (2000).

Sedimentary, metamorphic and igneous rocks, with ages ranging from Paleozoic to Quaternary are the geological units observed in Ankara (Yal and Akgun, 2013). Triassic rocks in the south, Jurassic–Cretaceous carbonates in the west, Upper Miocene–Lower Pliocene volcanics and fluvial–lacustrine clastic rocks in the north underlain the Ankara Basin. The Triassic basement is composed of dark brown greywacke, black shale and diverse sized carbonate blocks (Kocyigit and Turkmenoglu, 1991). Yalincak formation, consisting of three main lithofacies from bottom to top, namely, debris flow conglomerate, braid plain conglomerate and sandstone and clay bearing finer clastics of floodplain origins, basin fill of Ankara city (Kocyigit, 1991). Detailed and recent information about Ankara city can be found in Yal and Akgun (2013) and Kockar and Akgun (2012). Sariaslan et al. (1998) presented detailed information about the regional geology of Ankara city and neighboring Dodurga region.

The geological unit around the drilling region in Manisa city consists of chaotically deformed upper Maastrichtian–Lower Paleocene graywacke and shale with blocks of Mesozoic limestone, mafic volcanic rock, radiolarian chert and serpentinite (Erdogan, 1990; Okay and Siyako, 1993; Okay et al., 1996; Okay and Altıner, 2007; Okay, 2008). More detailed information about the geologies of Manisa and Izmir cities can be found in Bozkurt and Oberhansli (2001) and Oner et al. (2010).

For all drilling work, lithological description of rock units was continuously identified and recorded during drilling operation. Dominant rock types commonly observed in the fields of all drilling sites were mudstone, claystone, conglomerate, sandstone, limestone, volcanic, greywacke, agglomerate, and siltstone.

Following the drilling work, rock mass, rock material and operational parameters such as rock material uniaxial compressive strength, RQD and discontinuity frequency were recorded in the database for the sites investigated. Uniaxial compressive strength values were determined in the laboratory by following standard and suggested test procedures of both American Society for Testing and Materials (ASTM, 1984) and the ISRM (1979). RQD values were determined from the cores of the field drilling operation as a percentage of the drill core pieces in lengths of 10 cm or more.

The available data regarding machine property and operational parameters are pump pressure, pump volume, pressure loss, bit load and bit rotation. Operational parameters such as bit load (BL) and bit rotation (BR) of the main drilling machine body were recorded from the respective measurement gauges on the rig.

Overall, the total length of logged drill core covered in the database is approximately 1 km. The recorded rock material, mass properties and drilling machine operational parameters including penetration rates (PR) are given in Table 1. A typical example drill hole log which belongs to Manisa-Maldan region is given in Fig. 2.

3. Selection of model parameters and analyses of data

Selection of the model parameters was mainly based on literature survey and statistical analysis. It was concluded that the most relevant parameters affecting the penetration rate was divided into two groups as the rock mass parameters and the machine properties. This was the case not only for drilling, but also for the other machine excavation activities (Bruines, 1998; Alvarez Grima et al., 2000).

Rock mass properties are determined by combining rock material parameters and discontinuity structure of the rock mass. The most important rock material property in the database is the uniaxial compressive strength which is commonly the main design parameter for engineering structures. Uniaxial compressive strength is directly or

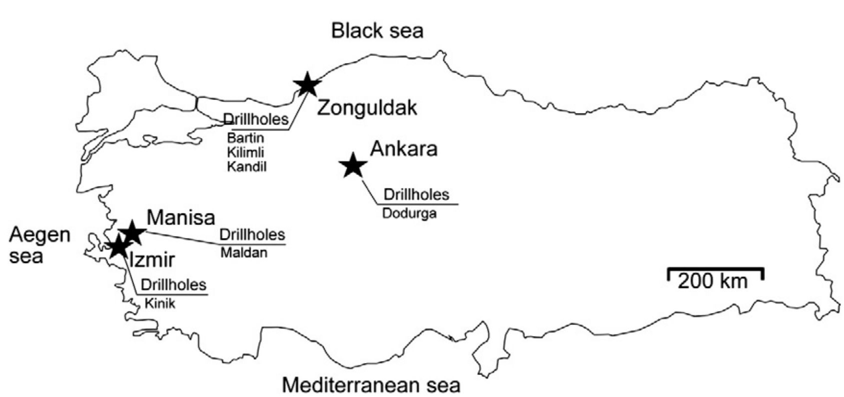

Fig. 1. Location of the database related drilling operations on sketch map of Turkey.

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