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GEOSCIENCES

Examining of rock drilling properties in underground metal mine excavation

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Abstract: In underground metal mines, drilling and blasting is widely used production method. Drilling holes is especially a time consuming operation. The aim of this study is to examine and analyze drilling operation and its duration in underground ore and dead rock. Drillability experiments are carried out on samples taken from the field. In core sampling two different types of core samples are taken whether it is parallel or perpendicular to ore bedding and dead rock. Results of drillability experiments are compared between the two types of core samples. DRI values are found to be 51 and 47 for the parallel and perpendicular core samples to ore bedding, respectively. DRI values for the parallel and perpendicular core samples to dead rock bedding are found to be 57 and 55 for the, respectively. In addition, graphs of drilling speed and drilling depth belonging to ore and dead rock are analyzed. It is examined that drilling speed increases steadily to maximum point in the first 5sec. and stays stable after that point. Therefore, it is concluded that production galleries and holes which are formed parallel to bedding would increase production efficiency.

Key words: Drillability, brittleness, bedding types, rock mechanics.

INTRODUCTION

The main objectives in drilling blasting operations, excavation operations of mines and tunnel excavations are achieving the best efficiency, keeping the excavation equipments in good shape and reduced wearing. When designing an excavation system, in order to achieve a good excavation performance, rock mass properties, physical and mechanical properties, drillability and properties of rock formation should be identified. If geological properties and parameters of the drilling machine are not consistent, there may occur important difficulties. In case of incorrect equipment selection, project may not be completed on time and costs may increase enormously which is undesirable. Therefore, as well as geological formation, physical and mechanical properties, drillability and corrosion of rock formation should be considered in detail.

Drillability is defined as the advance depth of drilling bit in rock formation. In other words, it is the degree of easiness/hardness in drilling the rock. Drilling speed is measured centimeters moved in the rock formation per minute. Therefore, drillability and drilling speed can be defined as the same concept. Drillability can be analyzed under two parts as controllable and uncontrollable factors. Controllable factors are machinery, drilling equipment, energy transfer in drilling equipment and selection of drilling bit. Uncontrollable factors are geological variables, geomechanical properties of rock and rock mass properties. Most researchers have studied on drilling rate index for selection of the most proper excavation or drilling machine and investigated the relationship between rock mechanical properties and drilling rate index (Thuro 1997, Tumac et al. 2007, Altindag 2002, Kahraman 2002, Dahl 2003, Hoseinie et al. 2008, Moein et al. 2014, Ceryan 2014, Ataei et al. 2015, Taheri et al. 2016, Ozfirat et al. 2016, Yaralı 2017, Yetkin et al. 2016, Rostami & Chang 2017, Yenice et al. 2018).

In this study, the raw data set obtained from the experimental works is used to investigate the effect of vertical and parallel bedding type on ore and dead rock drillability. At the end of the study, the relationships between drilling speed and drilling depth for different bedding types on ore and dead rock are determined obviously. Results show that to obtained more efficient production, processes of drilling and drift excavation should be done considering parallel bedding type for ore and dead rock.

MATERIALS AND METHODS

Case study

The underground ore mine from which the samples to be used in this study were taken lies 70 km east of Izmir and 15 km northwest of the small city Bayindir. The mine location and view from the mine heading can be seen in Figure 1.

The area under study is located in a formation called the North Menderes massive. Dominant rock types in the area are Muscovite and Chlorite Schist. There are Quartz band lenses and Calcareous Schists around. General strike of these Schists are in north-east direction and they dip towards south at an angle of 15-25^o. The ore samples contain 4.02% Pb and 7.48% Zn in average.

Test procedure

In the study, properties of the specimens given below are determined. These properties are unit weight (UW), density (D), compactness ratio (CR), porosity (n), water content (WC), water absorption percent by weight (WAW), water

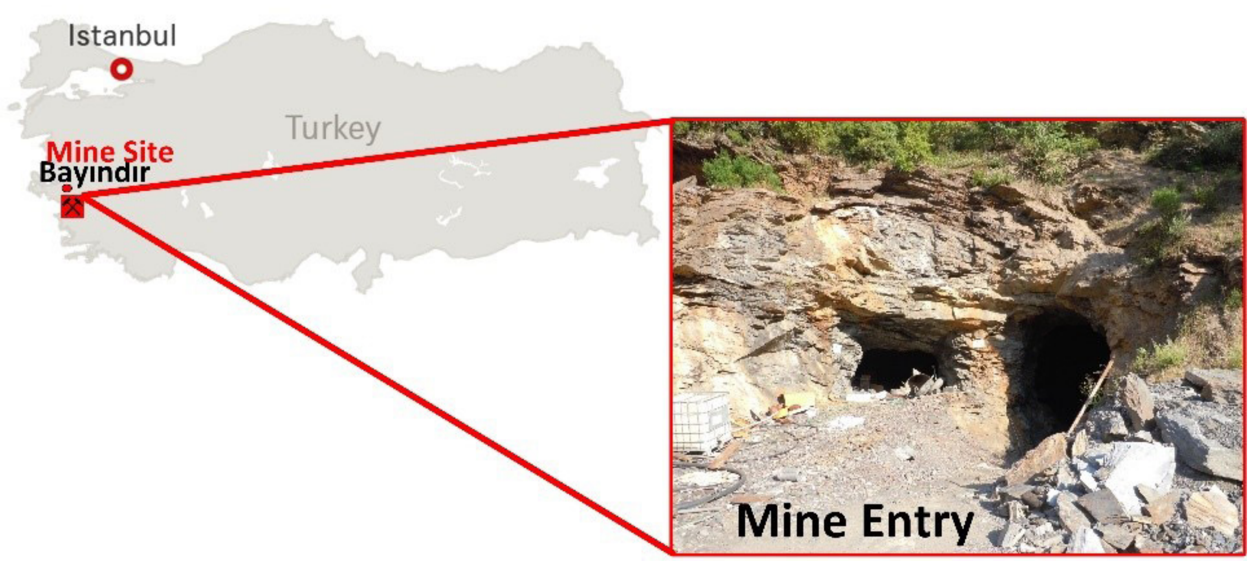

Figure 1. Location map of mine area.

absorption percent by volume (WAV), uniaxial compressive strength (UCS), Schmidt hardness (SH), brittleness test (BT), Sievers'J test (ST) and drilling rate index (DRI). In calculation of strength parameters, experiments are carried out on samples which are parallel or perpendicular to ore/dead rock bedding. The aim is to examine the effect of bedding direction on ore and dead rock mechanical properties. Photographs from experiments can be seen in Figure 2.

Unit weight is calculated by proportioning mass to volume. Volume of the pores is included in the total volume of rock. Density has same calculation with unit weight but in density calculation, volume of pores is removed from total volume of rock. Compactness ratio is calculated via porosity value and it is important in terms of strength of rock. Water content is be directly proportional to porosity. If the porosity increases, water content also increases. Water absorption percent by weight and volume is an important parameter for rocks and likewise it is be directly proportional to porosity. UCS is the main parameter in evaluating strength of rocks. Uniaxial compression tests are performed on trimmed cylindrical core samples, which are prepared according to ISRM 2015 standards and have a length-to-diameter ratio of 2.0–2.5. The Schmidt hammer hardness test is quick, cheap and easily applicable. In todays, Schmidt hammer test is widely used to predict the uniaxial compressive strength of rocks, the performances of excavating machines, advance speed of drilling machines.

The brittleness test gives a good measure for the ability of the rock to resist crushing by repeated impacts. The aggregate volume of the rock sample tested corresponds to that of a 500 g aggregate with density of 2.65 g/cm^3 in the fraction 11.2-16.0 mm. The value S_{20} (Brittleness value, %) was found from the percentage of material passing the 11.2 mm mesh after aggregate had been crushed by 20 impacts in the mortar. The brittleness value was taken as the mean value of 2-4 tests. The Sievers'J miniature drill test is a scale for the surface hardness of the rock. The tests are run until the drill bit has completed 200 revolutions. An electronic micrometer is used for measuring the depth of drill holes Sievers'J value is calculated as the mean value of the depth of the miniature drill holes, measured in 1/10 mm (Yetkin et al. 2016). Ore and dead rock drilled in different direction to bedding are given in Figure 3.

The drilling rate index is found by intersecting the values obtained from brittleness and Sievers' J tests on the graph given in Figure 4. The drillability grade of the rock according to DRI classification is given in Table I.

Experimental study

In the laboratory, physical and mechanical experiments such as BT, SH, UCS, UW, D, CR, P, WC, WAW, WAV, ST and DRI tests are carried out on the sample cores which are taken from mine field. The geomechanical test results carried out on ore and dead rock in different bedding direction can be seen in Table II. Physical test results are given in Table III.

According to the experimental results given in Table II, UCS values of samples perpendicular to bedding are greater than UCS values of samples parallel to bedding. These results also support drillability experiments results. Therefore, it can be said that especially dead rock formation is more suitable to drilling and excavation in parallel to the bedding direction. Since similar joints do not exist in ore zones, it would not be possible to do effective excavation or drilling hole in rock joints.

Sievers'J, brittleness experiment results for the perpendicular and parallel core samples are given in Tables IV and V.

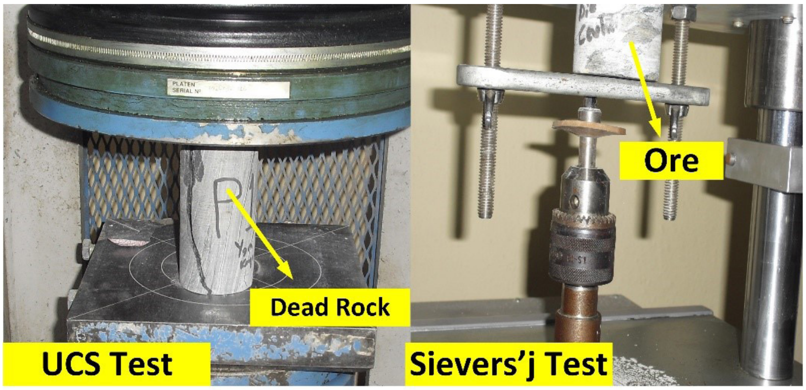

Figure 2. UCS and Sievers'J Tests (UCS: Uniaxial Compressive Strength).

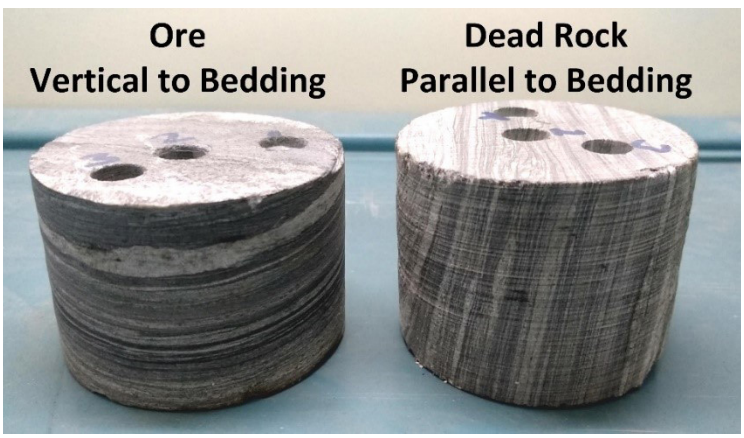

Figure 3. Ore and dead rock drilled in different direction to bedding.

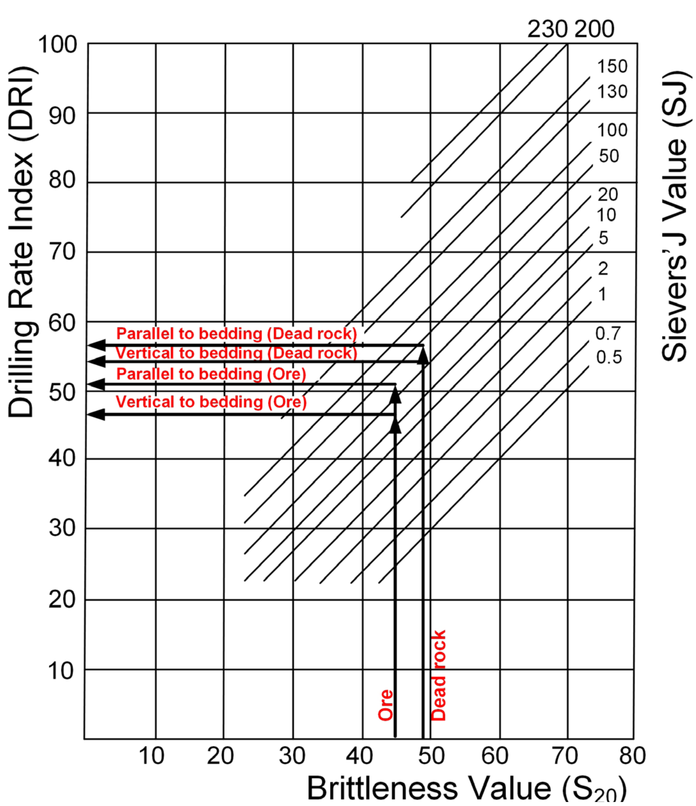

Figure 4. DRI chart (Dahl 2003).

Table I. Classification categories of DRI (Dahl 2003).

Category	DRI
Extremely low	≤25
Very low	26–32
Low	33–42
Medium	43–57
High	58–69
Very high	70–82
Extremely high	≥93

Table II. Geomechanical properties of ore and dead rock in different bedding direction.

Formation	Loading Conditions	BV (%)	SH	UCS (MPa)	UCS Mean (MPa)
Ore 1	Vertical to Bedding	43.93	33.51	105.08	91.35
Ore 2				77.63	
Ore 1	Parallel to Bedding			89.43	83.25
Ore 2				77.06	
Dead rock 1	Vertical to Bedding	49.26	47.11	99.81	103.05
Dead rock 2				106.18	
Dead rock 1	Parallel to Bedding			48.10	43.31
Dead rock 2				38.52	

UCS: Uniaxial Compressive Strength, BV: Brittleness value, SH: Schmidt hardness.

Table III. Physical properties of ore and dead rock in different bedding direction.

Formation	Loading Conditions	UW (g/cm^3)	D (g/cm^3)	CR (%)	n (%)	WC (%)	WAW (%)	WAV (%)
Dead Rock 1	Parallel to Bedding	2.75	2.78	98.72	1.28	0.06	0.17	0.05
Dead Rock 2		2.74		98.57	1.43			
Dead Rock 1	Vertical to Bedding	2.74		98.45	1.55			
Dead Rock 2		2.74		98.44	1.56			
Ore 1	Parallel to Bedding	3.12	3.26	95.52	4.48	0.06	0.09	0.03
Ore 2		3.26		99.98	0.02			
Ore 1	Vertical to Bedding	3.19		97.69	2.31			
Ore 2		3.07		94.10	5.90			

UW: Unit weight, D: Density, CR: Compactness ratio, n: Porosity, WC: Water content, WAW: Water absorption percent by weight, WAV: Water absorption percent by volume.

Table IV. **Average drilling depths and drilling speeds for different bedding conditions.**

Ore	Vertical Position to Bedding	
	Mean Values	
	Sievers'J Value (1/10 mm)	Drilling Speed (mm/s)
	17.88	0.038
	Parallel Position to Bedding	
	Sievers'J Value (1/10 mm)	Drilling Speed (mm/s)
	35.13	0.074
Dead Rock	Vertical Position to Bedding	
	Sievers'J Value (1/10 mm)	Drilling Speed (mm/s)
	29.04	0.04
	Parallel Position to Bedding	
	Sievers'J Value (1/10 mm)	Drilling Speed (mm/s)
	43.55	0.14

Table V. **Drillability (DRI) values of Ore and Dead rock.**

Formation types	Sievers'J value (1/10 mm)	Brittleness value (%)	Drilling Rate Index
Ore -Vertical to Bedding	17.88	43.93	47
Ore -Parallel to Bedding	35.13		51
Dead Rock -Vertical to Bedding	29.04	49.26	55
Dead Rock -Parallel to Bedding	43.55		57

DISCUSSION AND RESULTS

In this study, rock mechanics tests are performed on samples taken from an underground lead-zinc ore mine near Bayindir. The results obtained are given in Table II, Table III, Table IV and Table V. From these tables, it can be seen that the uniaxial compressive strength values of the specimens are between 38.52 MPa and 106.18 MPa, the unit weight values are between 2.74 gr/cm^3 and 3.26 gr/cm^3, and the Schmidt hardness values are between 33.51 and 47.11, compactness ratio values are between 94.10 and 99.98, porosity values are between 0.02 and 5.90. Water contents are found as 0.06 for dead rock and ore. DRI values of ore and dead rock are found as 47 and 55 for vertical position to bedding and found as 51 and 57 for parallel position to bedding respectively. According to the classification table given in Table I, the ore and dead rock can be classified as medium DRI rock.

From Table II and Table III, it can be seen that SH value for ore is 33.51. Average UCS of ore is 87.3 MPa and average unit weight is found to be 3.16 gr/cm^3 which is nearly 31 kN/m^3. When these values are positioned on Figure 5, estimated

UCS value for ore is found to be 85 MPa. The experimental UCS result and the estimated UCS value from shore hardness support each other with 97.36% ratio (Experimented UCS=87.3 MPa, estimated UCS=85 MPa).

Similarly, for dead rock, average UCS value is found to be 73.18 MPa and unit weight is 2.74 gr/cm^3 which is equal to 27 kN/m^3. Looking at Figure 5, these values correspond to estimated UCS value of 100 MPa. The estimated and experimented UCS values support each other with 73.18% ratio (Experimented UCS=73.18 MPa, estimated UCS=100 MPa). Therefore, it can be understood that shore hardness experiment results are accurate.

In the following Figure 6, the relationships between drilling speed and drilling depth for different bedding type on ore and dead rock are given.

According to Figure 6, in drilling operation which is perpendicular to bedding, bit drills the hole within first five seconds and bit wearing occurs. Therefore, drilling speed decreases after five seconds. Similar results are achieved in Dahl et al. 2007 and it is stated that highest efficiency is achieved in first five seconds of drilling operation. On the other hand, in drilling operation which is parallel to ore/dead rock bedding, bit wearing is small due to easier drilling and hence higher drilling speeds can be achieved (Figure 6). In this study, similar to Thuro 1997, Tumac et al. 2007, Altindag 2002, Kahraman 2002, Dahl 2003, Hoseinie et al. 2008, Moein et al. 2014, Ceryan 2014, Ataei et al. 2015, Taheri et al. 2016, Ozfirat et al. 2016, Yaralı 2017, Yetkin et al. 2016, Rostami & Chang 2017, Yenice et al. 2018, drilling efficiency will be increased and bit use will be decreased.

Another important result is to drill holes parallel to bedding in ore and dead rock drilling operations. By this way, production efficiency can be increased and bit use can be decreased.

In Table VI, data belonging to three different types of drilling machines are taken as field data.

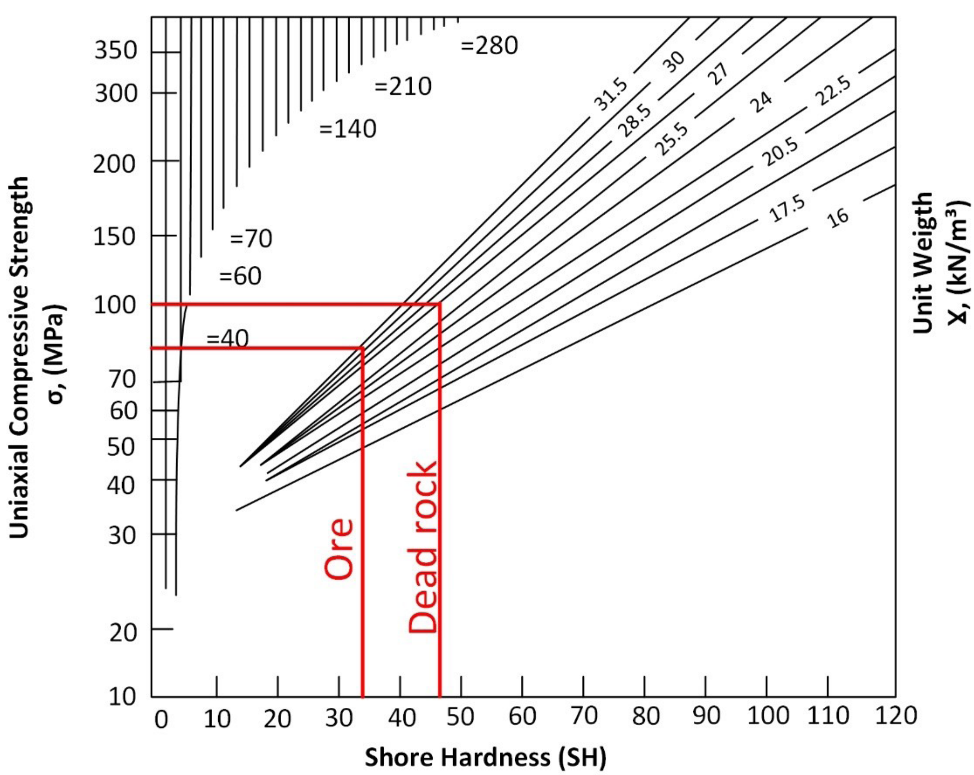

Figure 5. Approximation of UCS of ore and dead rock according to SH values.

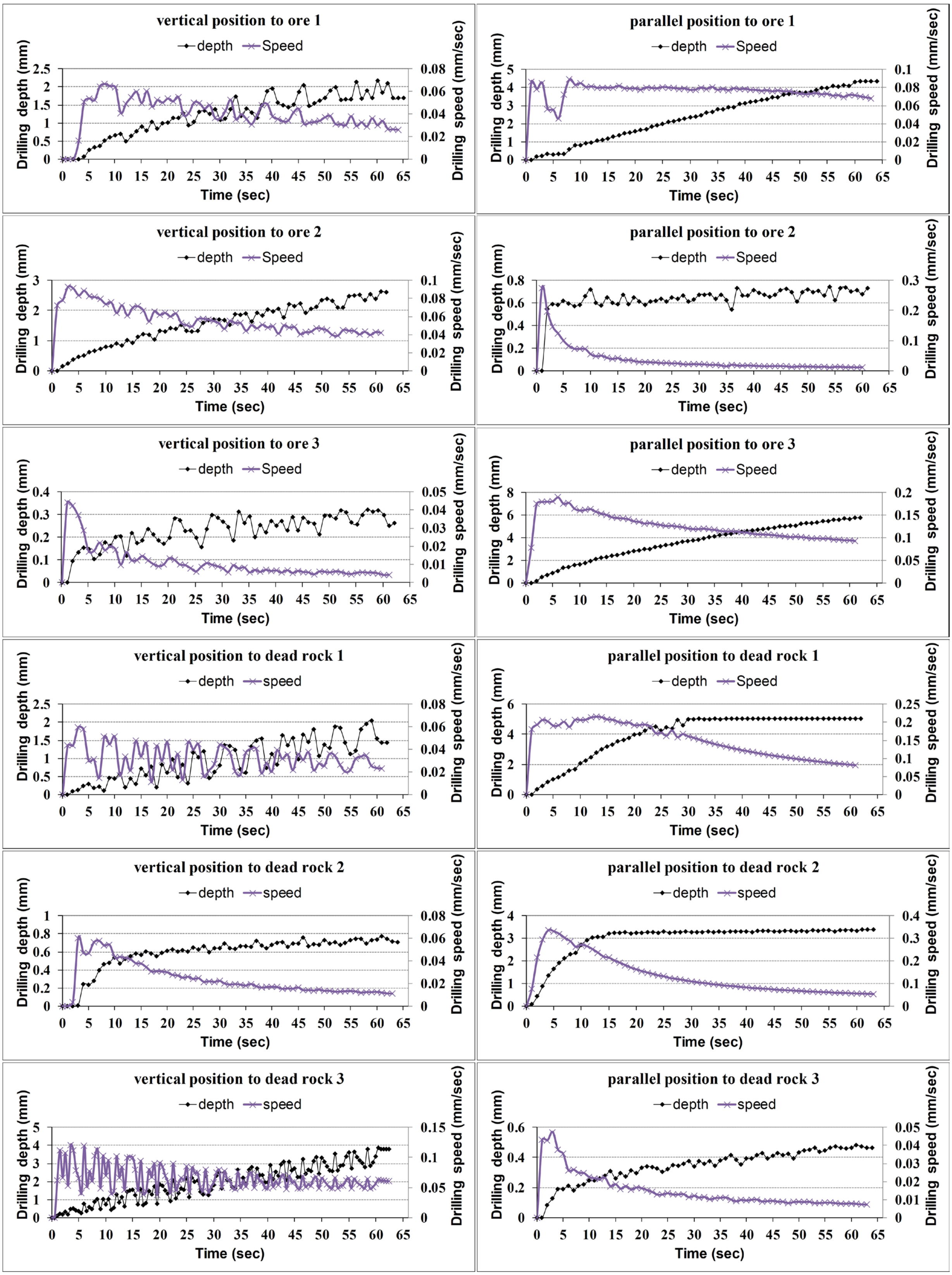

Figure 6. The relationships between drilling speed and drilling depth for different bedding types.

Table VI. Data belonging to drilling machine in the field.

Drilling Machine Type	Machine drilling time (minutes/1m hole)	Service life (number of holes)	Service life (m)
A	2-4	70-80	112-128
B	2-4	10-15	16-24
C	2-4	400-500	640-800

Drilling times are equal for all types of machines which is 2 to 4 minutes per 1 meter. Bit of type C is able to drill 400 to 500 holes within bit life. Looking at the values in Table VI, it can be said that when hole drilling is parallel to bedding, number of holes of type C bit may be increased to 800 to 1000 holes and service life may be increased to 1200 to 1600 meters.

CONCLUSION

One of the major problems in underground metal mining is to be unable to obtain desired drilling and excavation speeds during production and development phases. This situation causes time loss and low efficiency. In this study, drilling speed is estimated by experiments carried out on field samples. Effect of bedding types on drilling speed is analyzed. When drilling is perpendicular to bedding, drilling is performed within first five seconds of operation. After that point bit wears out. Dead rock and ore drilling values are examined according to bedding types. In the result, it is found that in order to increase efficiency and decrease bit use, hole drilling and production gallery development should be parallel to ore/dead rock bedding.

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