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Assessment of Effect of Rock Properties on Horizontal Drilling Rate in Marble Quarry Mining: Field and Experimental Studies

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Abstract

Rock drilling is one of the most important processes in the mining operations, which involves high costs. Deep knowledge of the drilling conditions and rock mass properties can help the optimum selection of drilling system, precise determination of type and number of drilling equipment, and accurate prediction of drilling rate. The above process leads to enhance the drilling efficiency and mining productivity. In this work, relationships between the rock the physico-mechanical properties and horizontal drilling rate (HDR) are investigated. For this purpose, HDR is firstly measured during the drilling process at the Malawi marble quarry mine, Islamabad-e-Gharb, Iran. Then core samples are prepared from the representative minor rock blocks to conduct the laboratory tests and evaluate the influence of rock properties on HDR. The experimental results prove that natural density (ρn), dry density (ρd), slake durability index (Id), Schmidt hammer rebound (SHR), compression wave velocity (Vp), point load index (PLI), uniaxial compressive strength (UCS), and modulus of elasticity (E) have inverse relationships with HDR. Conversely, HDR has a direct relationship with porosity (n), water content (Wa), Los Angeles abrasion (LAA), and Poisson ratio (ν). Generally, it is proved that HDR is more associated with the rock's physical properties than the mechanical characteristics. Moreover, sensitivity analysis confirm that n and ρd are the most and least effective variables on HDR. Furthermore, new optimum empirical equations with acceptable accuracy are proposed to predict HDR based on the statistical modeling. Finally, experimental verification analysis confirm the superiority of this study compared to the prior similar studies.

1. Introduction

The products of the marble quarry mines are the main used materials in the building industry, road construction, and other related industries. In order to improve the economics of these industries, optimization of the production process in these mines is essential. Indeed, any optimization in the quarry mining process increases the efficiency of production, and decreases the final product cost. Since the drilling process is an important operation in the quarry mining, optimization of the drilling rate (DR) can enhance the mining efficiency, and minimize its capital and operational costs. Generally, controllable and uncontrollable variables affect DR in rock drilling. The properties of drilling device are the uncontrollable variables, whereas the physico-mechanical and structural properties of rocks are the controllable parameters. As the optimum estimation of DR inherently affects the cost estimation of drilling projects and mine scheduling and development, hence, identifying the influential variables on DR is crucial for the successful planning of a drilling process. Especially in quarry mines, drilling task is a time-consuming operation, and the downward processes such as cutting and slabbing operations associated with the termination of the drilling process. Consequently, estimation of the optimum drilling rate is very important in quarries, and can affect the success of downward operations. In the surface and quarry mining operations, total drilling costs can be estimated using the predictive empirical relations. Thus knowledge of the drilling

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parameters and rock mass properties can help an optimum estimation of DR or penetration rate (PR), an ideal selection of drilling tools, and a desired determination of type and number of drilling equipment. This leads to an accurate assessment of drilling efficiency and the production capability in the mining operation. Furthermore, this is very crucial in quarry mining during the mine scheduling and cost estimating. Considering the importance of this issue, the relationship of DR with different rock properties was studied by numerous researchers [1-5], which are briefly outlined here.

Reviewing the previous studies showed that the relationships of DR with various rock properties i.e. UCS, E, V_p, PLI, ρ_n, SHR, LAA, n tensile strength (σ_t), hole diameter (D), and Mohs hardness (MH) were investigated [6-12]. According to these reviewed literatures, a direct relation of DR with LAA and n was achieved. In contrast, an inverse relation of DR with D, UCS, σ_t, E, MH, PLI, SHR, and V_p was acquired. Particularly in marble quarry mining, the relation of DR with rock properties was studied by different researchers [13-22]. This literature review showed that field investigation, experimental testing, numerical method, and analytical modeling were used to investigate the relationship of DR with rock properties. Also the above-mentioned publications demonstrate the significance of the current study and the impact of the efficiency of drilling operations on the mine outputs. On the other hand, the whole rock properties (i.e. physical and mechanical characteristics) weren't simultaneously considered in DR modeling. In addition, there are a few studies on the drilling rate investigation in quarry mining, particularly in the marble types. Furthermore, the previous studies focused on the vertical drilling rate, and the effect of rock properties on the HDR was ignored. Given that, this research work is conducted to cover the above weaknesses for decreasing the mining final operation cost and improving their related industries' economics.

This study aims to investigate the inherent relation of HDR with the rock properties. Also determining the most effective rock properties on HDR is fulfilled using statistical modeling and sensitivity analysis. For this, the required data for HDR calculation (drilling length and time) was collected during the drilling operations of the Malawi marble quarry mine, Islamabad-e-Gharb, Iran. Then the related minor blocks were provided and transferred to the laboratory for core specimen preparing and conducting the physical and mechanical tests. Accordingly, a suitable database was supplied to perform the parametric analysis and statistical modeling.

2. Malawi Marble Quarry Mine

The Malawi marble quarry mine is considered as the case study in the current study. In the Malawi mine, about 1.25 Mt reserve is measured, which is extracted by the yearly extraction of 8,000 tons. This mine is situated in the Islamabad-e-Gharb, Kermanshah province, Iran. It is located at the longitude of 46º 36′ 35.033″ and latitude" of 34º 3′ 53.41″ in the southeast of Islamabad-e-Gharb city, at the left side of the Islamabad-e-Gharb-Homeil road. The geographical location and the access paths to the mine area are represented in Figure 1. Also the mine environment and its working bench are shown in Figure 2.

diameter can be drilled by this machine. However, the frequently used hole diameter in this mine is 76 mm. Also cutting and splitting the rock blocks from the bench face and preparing the slabs are conducted by using the diamond wire cutting device. Furthermore, water flow is applied for cooling the diamond wire during the cutting process.

3. Measurements

3.1. In-situ

For HDR measurement during the drilling operations in the Malawi marble quarry mine, time and depth of drilling were calculated during the horizontal drilling. According to this process, 20 HDR datasets were provided. Some of these datasets along with the geological conditions of the drilled blocks are given in Table 1. Then sufficient minor block samples with 20 × 25 cm dimensions were collected from the related main drilled blocks and transported to the laboratory for preparing core specimens and conducting the required physico-mechanical experiments.

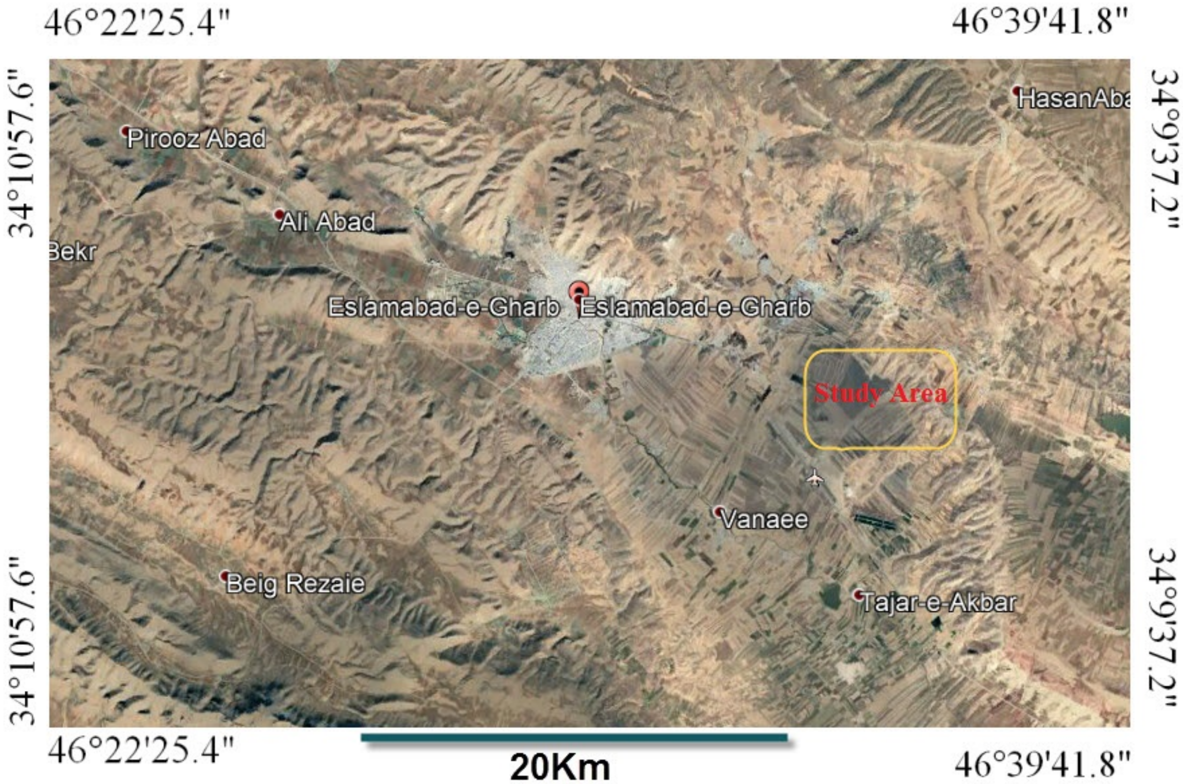

Figure 1. Geographical location of the studied mine.

Figure 2. Malawi mine environment and its working bench.

Table 1. Some HDR datasets along with the geological conditions of drilled blocks.

No.	Drilling Length (m)	Drilling time (h)	Geological conditions
1	6	2.5	Pure rock
2	6	3	With some soil
3	6	3	With some soil
4	10	2	Pure rock
5	5	1	Pure rock

From the structural viewpoint, the studied mine is located in the folded Zagros zone. The general trend of this zone is in the northwest-southeast direction. There are sedimentary rocks in the mine area, which are mostly chemical formations comprising marl and shale structures. Indeed, chemical sediments exist in the mine area, and any magmatism activity can't be observed. The geological age of the mine area is related to the upper Eocene containing Shahbazan rock types. From a lithological point of view, the Malawi marble quarry mine contains dolomite rock type.

Malawi marble quarry mine is extracted in the form of open-pit quarry mining. The pneumatic RASOL drilling machine is used for hole drilling in this mine. Vertical and horizontal hole types with 70-152 mm

3.2. Experimental

In order to conduct the experimental tests, standard cylindrical core specimens were prepared on the collected minor blocks from the mine. The coring machine and some of the provided core specimens are represented in Figure 3. It should be noted that cylindrical specimens were prepared with 76 mm diameter to match the in-situ drilled hole's diameter at the studied mine (Figure 3b). After that, two ends of the specimens were cut by cutting tool in the form of suggested standards and polished by a polisher device. After the specimens preparing, various required experimental tests were conducted to measure the physico-mechanical properties of specimens according to the suggested methods by ISRM [23-25]. The measured properties of core specimens are natural (ρ_n) and dry (ρ_d) densities, porosity (n), water content (w_a), slake durability index (I_d), Schmidt hammer rebound (SHR), compression wave velocity (V_p), Los Angeles abrasion (LAA), point load index (PLI), uniaxial compressive strength (UCS), modulus of elasticity (E), and Poisson ratio (ν). The used devices to perform the related laboratory experiments are shown in Figure 4. Sufficient explanations of these experiments were provided in the previous literatures [23-27]. Therefore, the additional descriptions aren't given in the current study.

(a) (b)

Figure 3. a) Coring machine b) provided core specimens.

(a)

(b)

(c)

(d)

(e)

(f)

Figure 4. Used experimental devices: a) Instruments to measure I_d; b) Proceq tool to measure SHR; c) PUNDIT tool to determine V_p; d) a device for LAA measurement; e) Utilized device to measure PLI; f) Measuring device of UCS, E, and ν.

3.3. Prepared data

Based on the conducted in-situ and experimental measurements, 20 reliable datasets were provided for parametric study and statistical modeling. The statistical descriptions of provided datasets for HDR modeling are given in Table 2.

Table 2. Statistical descriptions of provided datasets for HDR modeling.

Parameter	Symbol	Max	Min	Var.	Std dev.
Natural density (g/cm^3)	ρ_n	2.517	2.22	0.00838	0.09155
Dry density (g/cm^3)	ρ_d	2.45	2.21	0.00588	0.07671
Porosity (%)	n	2.11	0.43	0.1459	0.3820
Water content (%)	w_a	6.84	1.91	2.0112	1.4181
Slake durability index (%)	I_d	0.993	0.96	7.91E-5	0.008893
Schmidt hammer rebound (-)	SHR	73	46	45.7493	6.7838
Compression wave velocity (m/s)	V_p	4321	3651	38411.08	195.987
Los Angeles abrasion (%)	LAA	68.74	28.23	114.5243	110.7016
Point load index (MPa)	PLI	4.6	1.09	0.90528	0.95146
Uniaxial compressive strength (MPa)	UCS	65.12	12.96	197.7189	14.0612
Poisson ratio (-)	ν	0.39	0.2	0.002652	0.0515
Modulus of elasticity (GPa)	E	35.1	10.11	38.2837	6.1873
Horizontal drilling rate (cm/min)	HDR	8.23	2.88	2.5985	1.61201

4. Results and Discussion

4.1. Effect of rock properties on HDR

In this section, a parametric study (PA) was conducted, in which the influence of rock properties on HDR was investigated. In this analysis, the direct or inverse relation of HDR with each of the rock properties was determined. PA could help the better knowledge of rock properties relation with HDR, and is useful for the optimum selection of drilling tools. This process assists the best selection of drilling equipment consistent with each specific rock type, which can enhance the efficiency of drilling operations and mine productivity.

Here, PA was conducted to evaluate the relationship of rock properties with HDR. Accordingly, the intrinsic relationships of understudied rock properties with HDR are represented in Figures 5–16. As it can be seen from these figures, the ρ_n, ρ_d, I_d, SHR, V_p, PLI, UCS, and E variables have an inverse influence on HDR. Conversely, the n, W_a, LAA, and ν variables have a direct impact on HDR. Also it is concluded from these figures that the ρ_n, ρ_d, n, W_a, I_d, SHR, V_p, and LAA variables are more correlated with HDR compared to the other rock properties. Considering the above outputs, it can generally result that HDR is more correlated with the physical characteristics of rock than the rock's mechanical properties.

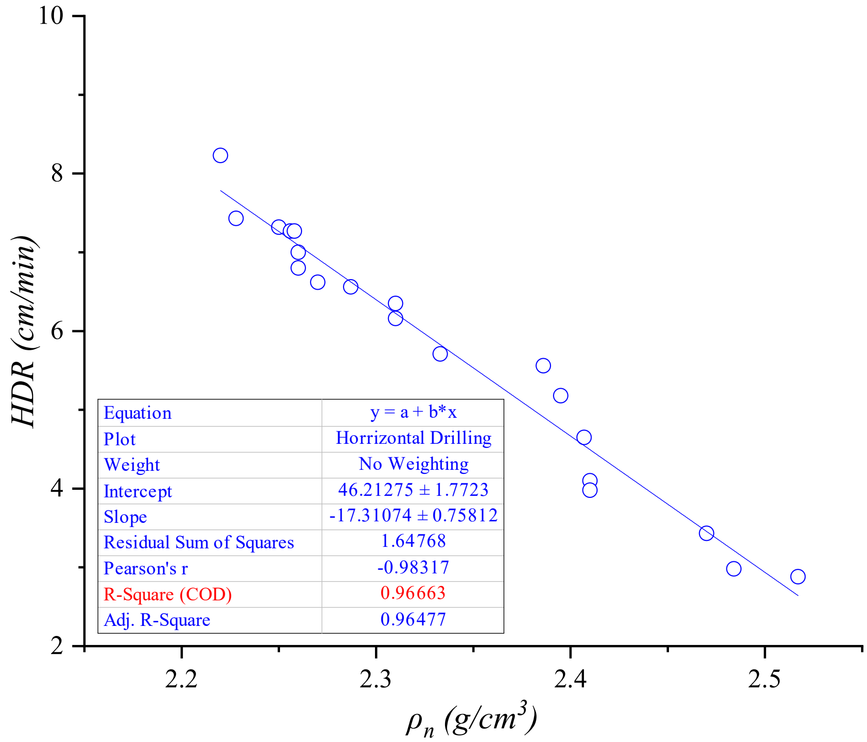

Figure 5. Relationship between HDR and natural density.

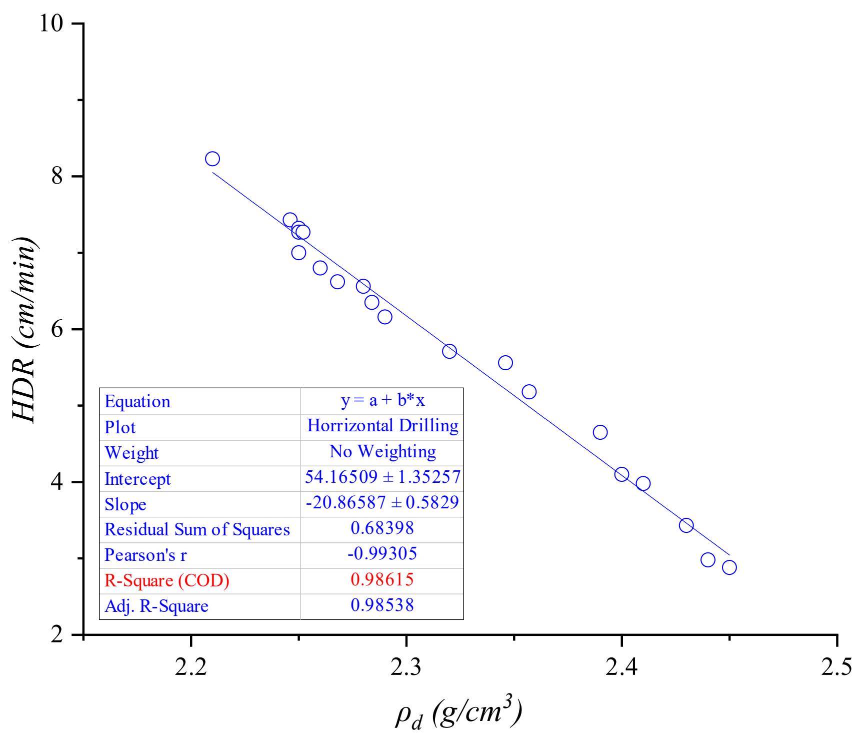

Figure 6. Relationship between HDR and dry density.

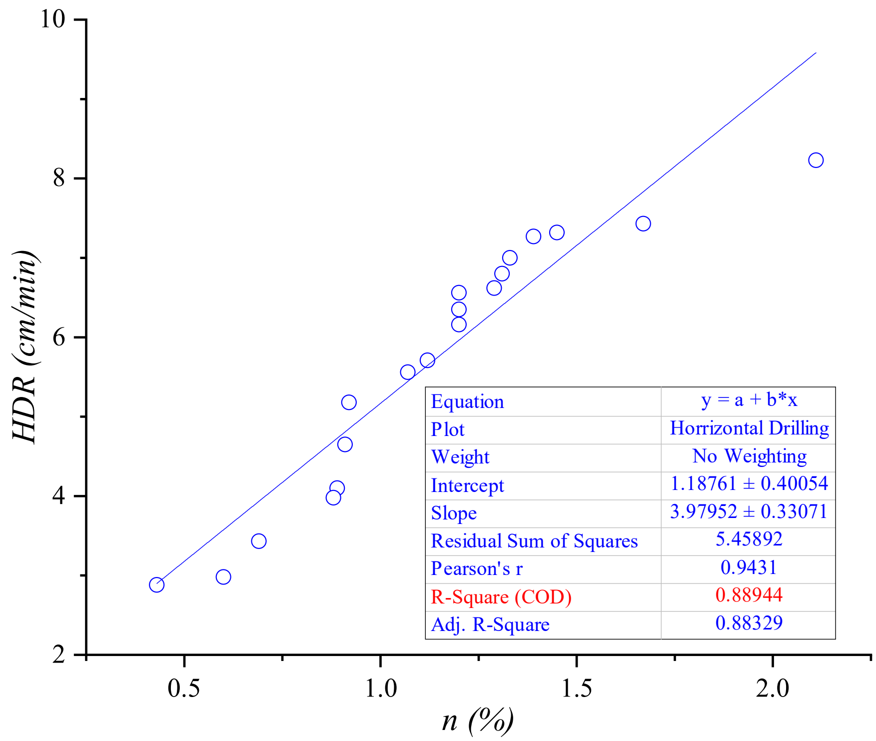

Figure 7. Relationship between HDR and porosity.

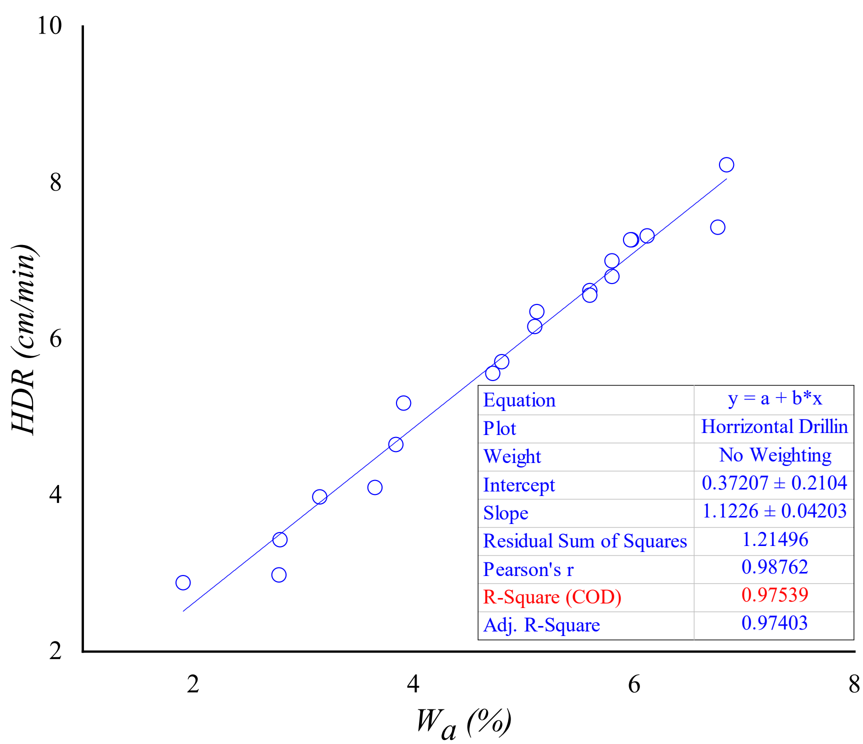

Figure 8. Relationship between HDR and water content.

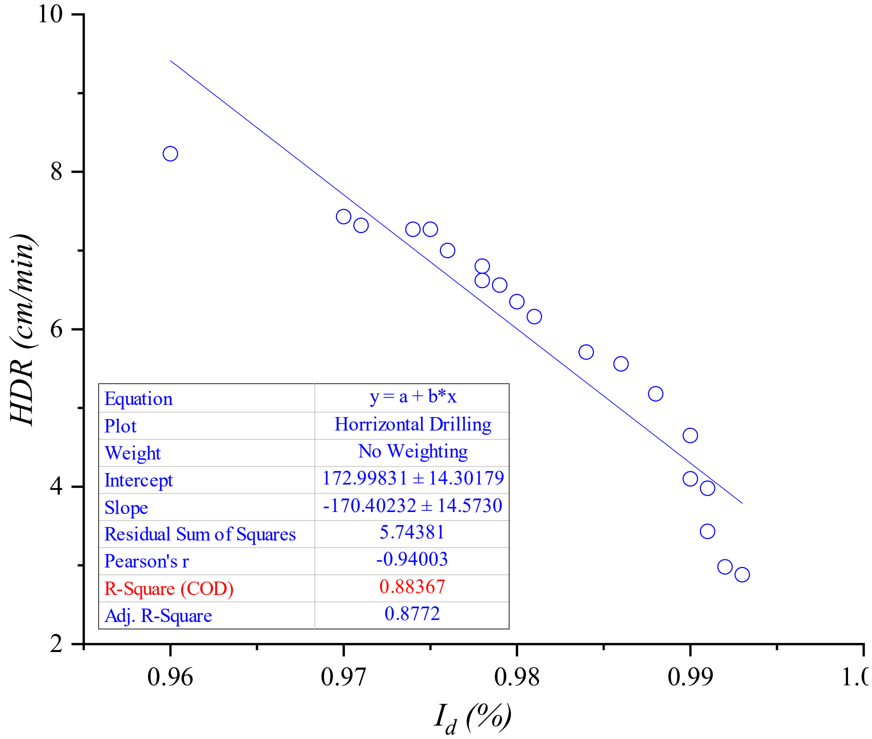

Figure 9. Relationship between HDR and slake durability index.

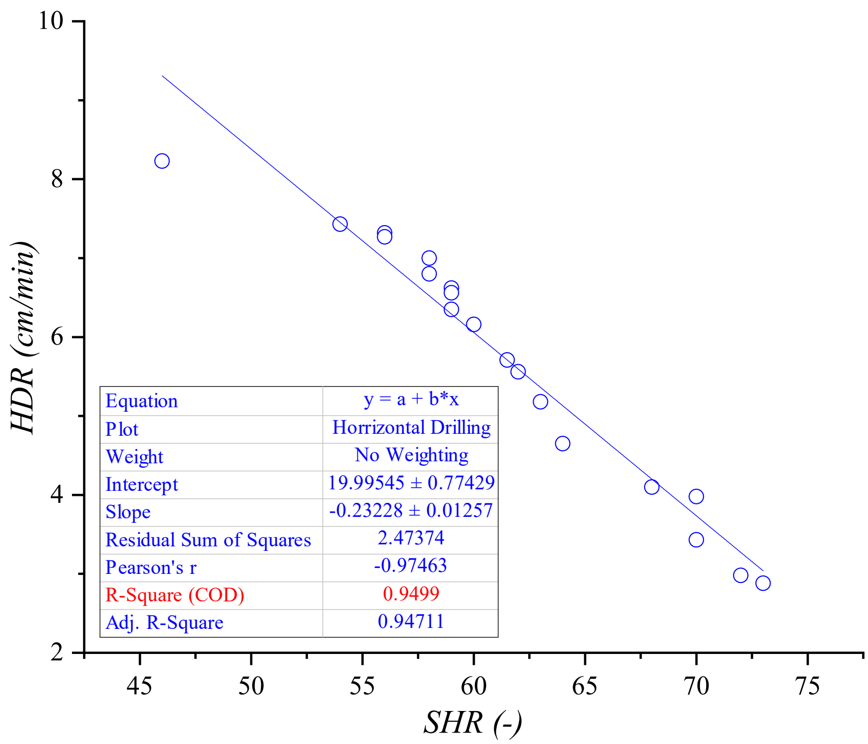

Figure 10. Relationship between HDR and Schmidt hammer rebound.

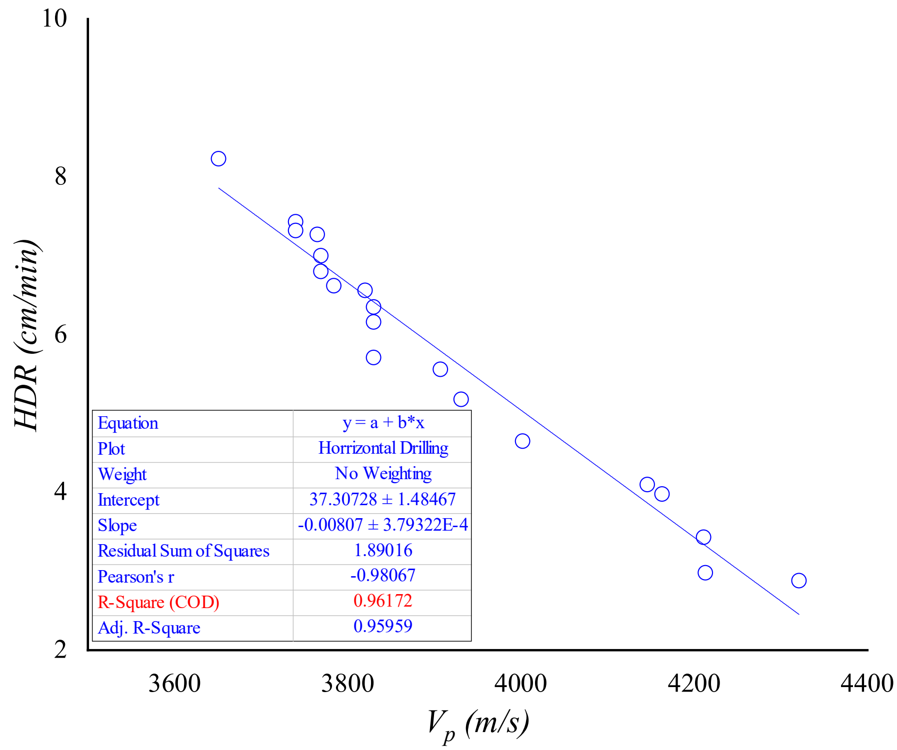

Figure 11. Relationship between HDR and compression wave velocity.

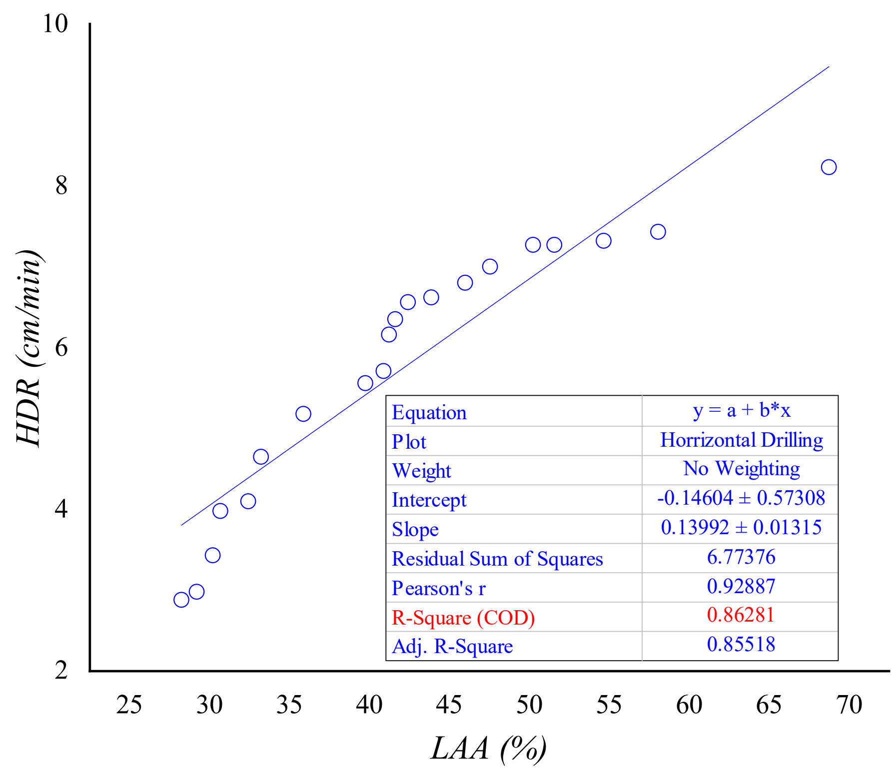

Figure 12. Relationship between HDR and Los Angeles abrasion.

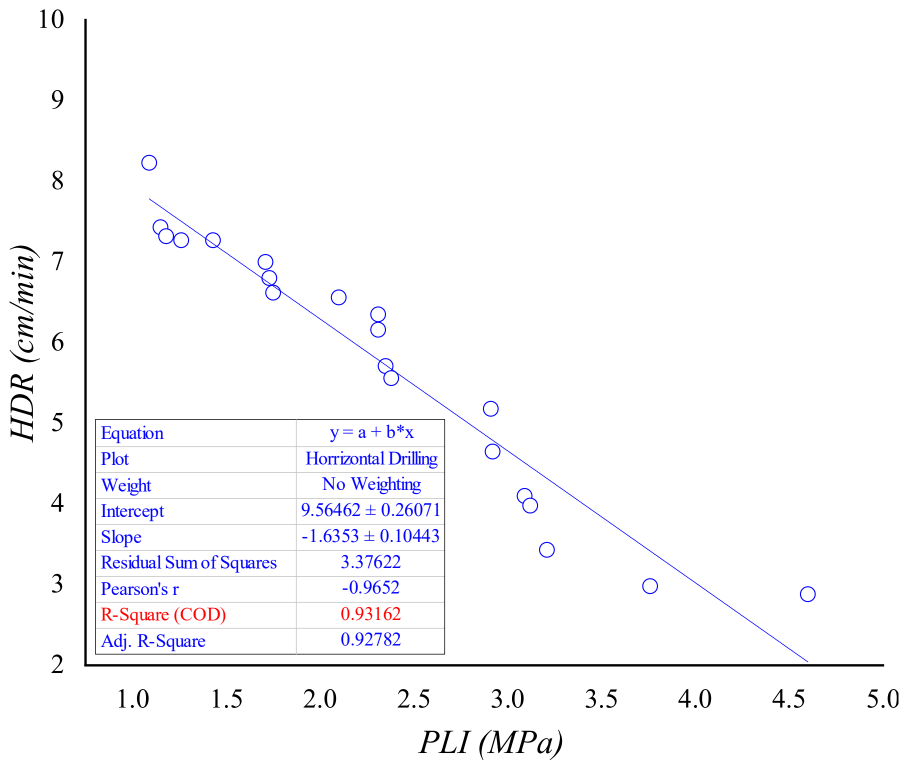

Figure 13. Relationship between HDR and point load index.

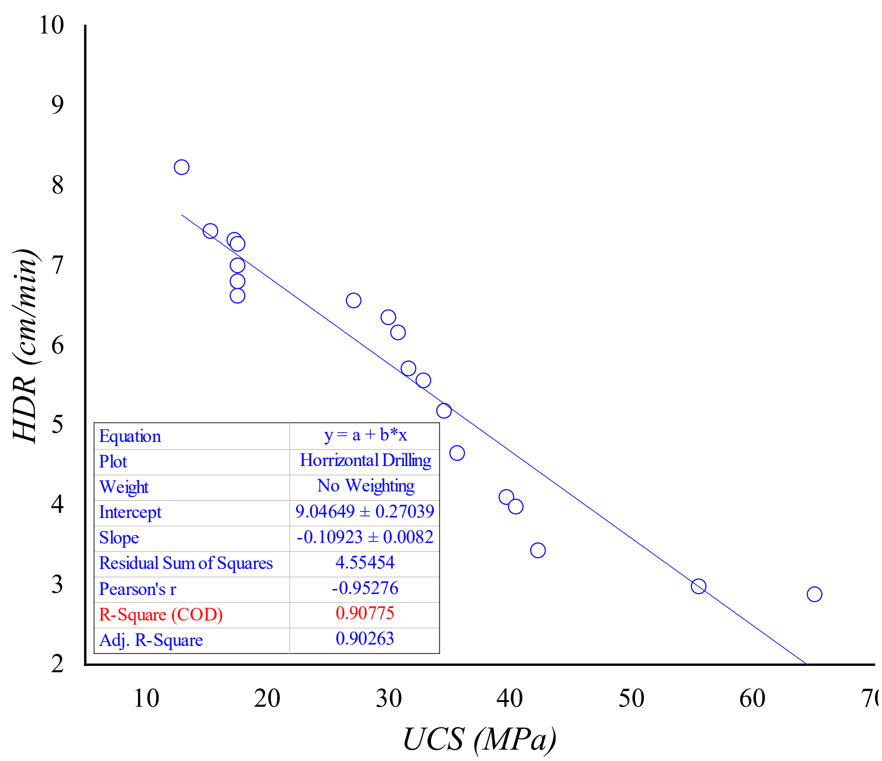

Figure 14. Relationship between HDR and uniaxial compressive strength.

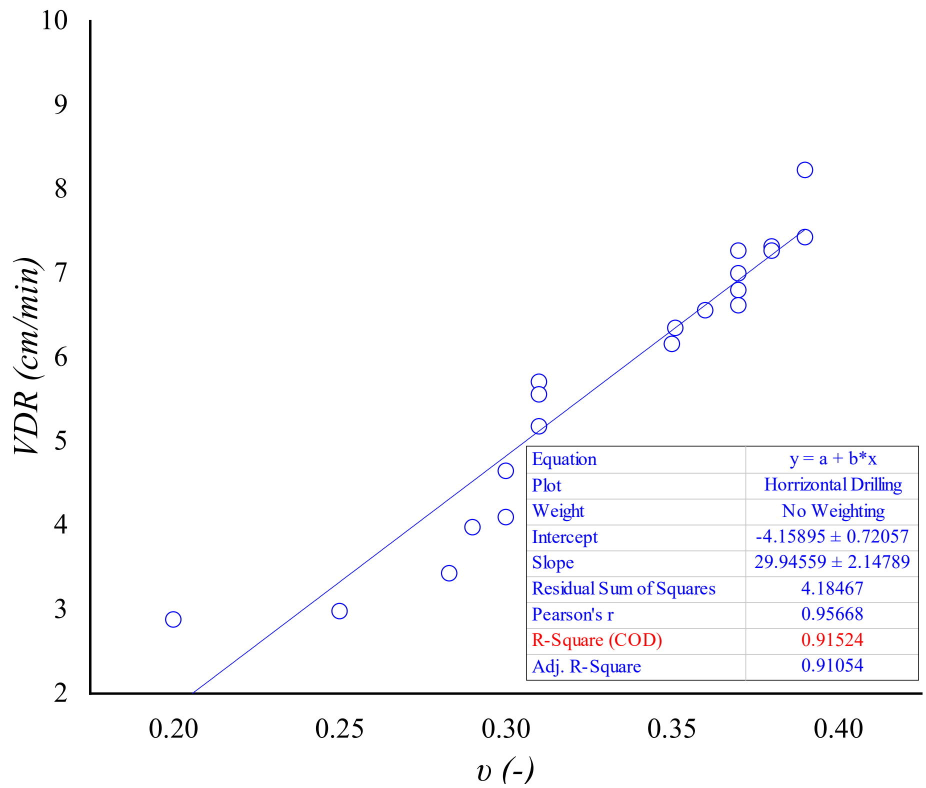

Figure 15. Relationship between HDR and modulus of elasticity.

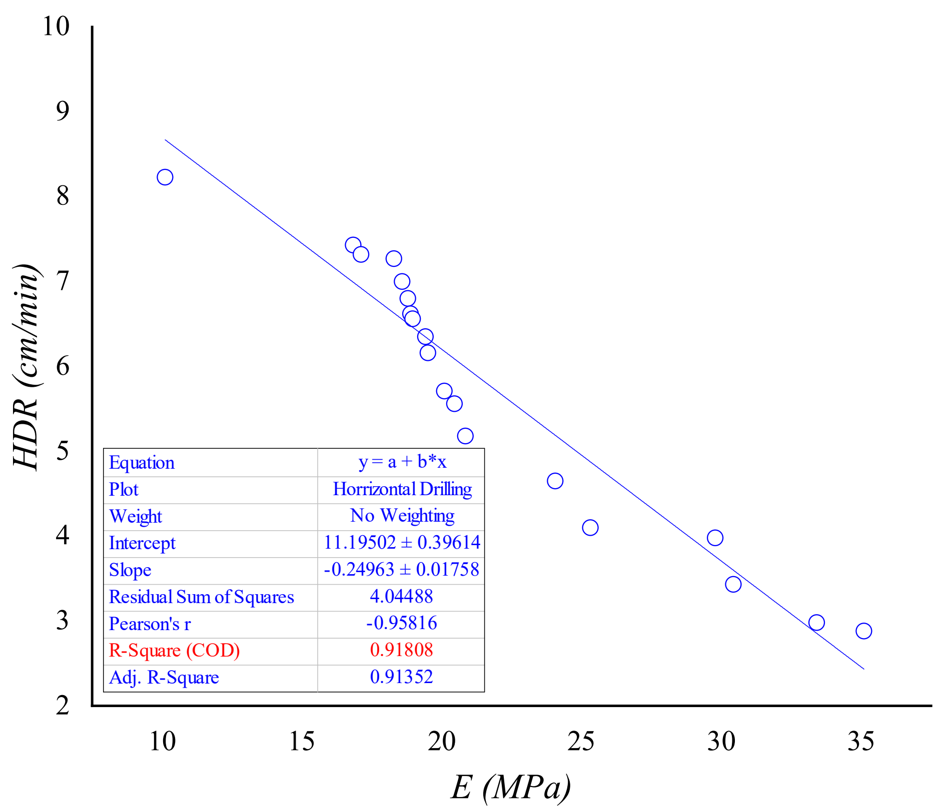

Figure 16. Relationship between HDR and Poisson ratio.

4.2. Sensitivity analysis

Here, sensitivity analysis (SA) was performed to evaluate the most and least effective rock properties on HDR. The SA process is usually conducted using two different methods i.e. conventional and novel approaches. In the conventional method, the influence of an understudied input variable on an output variable is acquired based on the changing of it and keeping constant the other input variables [28-32]. On the other hand, some developed analytical-based functions i.e. the cosine amplitude method (CAM) are applied for SA objectives in the novel methods [33-36]. In this work, multiple conventional SA was used to specify the influence values of rock properties on HDR. For this purpose, the changes of input variables (12 rock properties) and output variable (HDR) were firstly computed and standardized in the range of 0 to 100 percentages. After that, each input variable was changed separately against HDR and illustrated in linear contour. This process was repeated for all input variables, and the obtained inputs-output contour variations were depicted in Figure 17. The depicted contours in this figure identify the influence of rock properties on HDR, which are achieved from their variation percentages. Certainly, every contour specifies the relation of input-output variables in which the higher gradient of a contour related to an input rock property, the higher influence on the HDR. Quantitative values of contours gradient were computed from this conventional SA, and given in Table 3 to identify the inherent influence of rock properties on HDR. Based on Figure 17 and Table 3, it is proved that HDR has an inverse relationship with natural ρ_n, ρ_d, I_d, SHR, V_p, PLI, UCS, and E, and a direct relationship with n, W_a, LAA, and ν variables. Also it is confirmed that n and SHR are the most effective variables on HDR. Conversely, ρ_d and ρ_n are the least influential variables on the output. Nevertheless, the influences of E, PLI, and UCS variables on the HDR are considerable, and should be noticed in horizontal drilling operations. It is concluded from this conventional SA that these effective parameters should be more noticed in the horizontal drilling operations, especially in selecting the drilling tools requirements such as drilling device type, bit, wear, and casing.

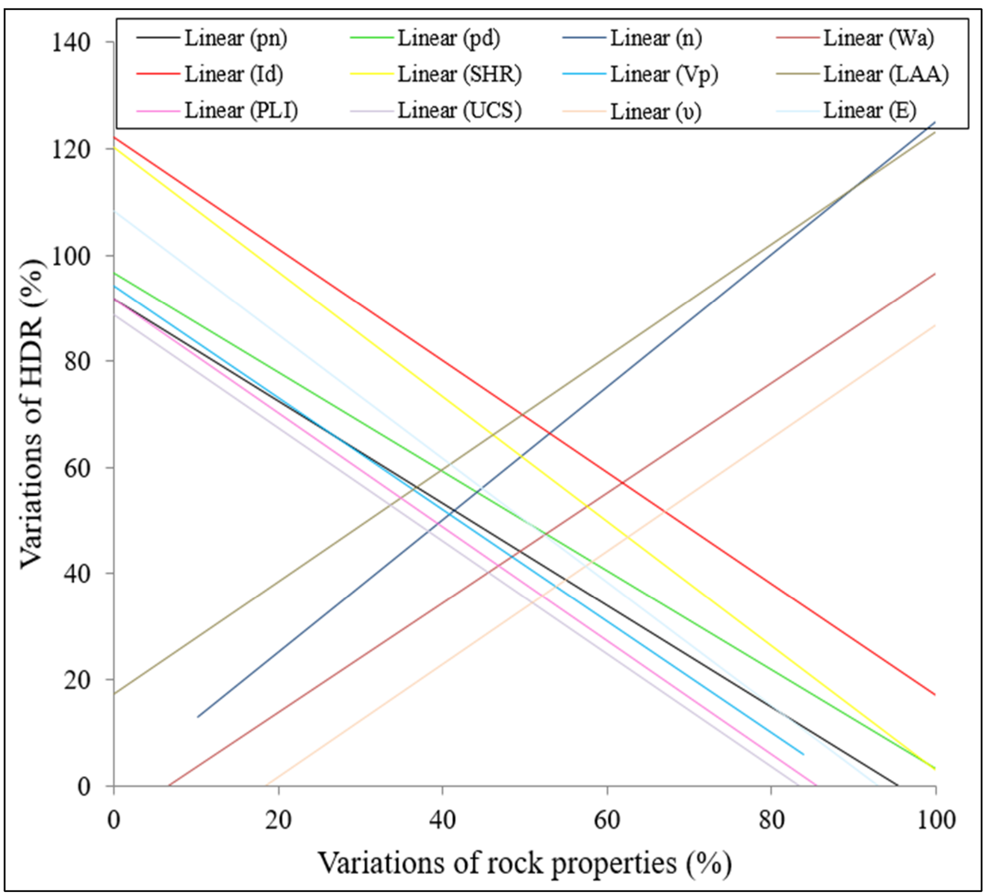

Figure 17. Results of SA based on the variations of input-output variables.

Table 3. Quantitative values of contours gradient concluded from the conventional SA to identify the influence of rock properties on HDR.

Variable	Contour gradient amount in SA	Variable relationship with HDR
ρ_n	-0.961	Inverse
ρ_d	-0.936	Inverse
n	+1.2476	Direct
w_a	+1.0345	Direct
I_d	-1.0511	Inverse
SHR	-1.1723	Inverse
V_p	-1.0521	Inverse
LAA	+1.0595	Direct
PLI	-1.0729	Inverse
UCS	-1.0649	Inverse
ν	+1.0635	Direct
E	-1.166	Inverse

4.3. Multiple regression analysis

Multiple regression analysis (MRA) between HDR and 12 rock properties was conducted here. In this MRA, constant value and coefficients between 12 rock properties and HDR, determination coefficient (R^2), Fisher-test factor (F), significance coefficient (Sig.), and standard error of the estimation values were obtained. The main outputs of MRA modeling for HDR estimation are given in Table 4. According to this table, the values of achieved Sig. is lower than 0.05, which confirm the meaningfulness of the developed MRA, as a confidence level of 0.95 is considered in the MRA modeling. In addition, the obtained value of R^2 from the MRA modeling of HDR are considerably near to 1, which proves the correctness of the performed MRA modeling between HDR and rock properties. Moreover, the high achieved value of F index demonstrates the good capability of this MRA modeling. Finally, the achieved value of standard error of the estimate from the MRA modeling is too low, which proves the high capability of the conducted MRA modeling.

Table 4. Main results of MRA for HDR estimation.

Dependent variable	Predictor	Coefficient	Summary results of MRA model			
			R^2	F	Sig.	Std. Error of the Estimate
HDR	Constant	-6.736	0.998	253.26	0.0	0.12731
	ρ_n	-4.225				
	ρ_d	-13.674				
	n	0.752				
	w_a	0.068				
	I_d	-57.623				
	SHR	-0.112				
	V_p	-0.002				
	LAA	0.028				
	PLI	-0.460				
	UCS	-0.009				
	ν	2.370				
	E	-0.026				

4.4. Empirical equations between HDR and rock properties

In order to develop the empirical relations between each of the considered rock properties with HDR, an analysis of variance (ANOVA) simulation was performed. For this purpose, five possible equations i.e. linear, polynomial, quadratic, exponential, power, and logarithmic types were firstly developed between HDR and each of the considered rock properties. To select the best predictive relation among these developed equations, the R^2, F, and Sig. indices were applied. Indeed, the outputs of ANOVA modeling were used to select the optimum equations between HDR and the considered rock properties. According to the acquired criteria from ANOVA modeling, the optimum equations to predict the HDR are given in Table 5. As it could be seen from this table, the quadratic and exponential equation types were identified as the best equations between HDR and different rock properties. However, the optimum exponential equation type was acquired only for HDR-E relation, and the quadratic polynomial equations were acquired as the optimum relations between HDR and the other rock properties. As a result, these best possible equations are suggested in this study to predict the HDR. These proposed equations can be applied to the other similar case studies as the predictive tools to optimize the drilling operations.

Table 5. Results of ANOVA modeling to discover the optimum equations between HDR and rock properties.

Inputs	Optimum equation type	Equation	R^2	F	Sig.
ρ_n	Quadratic	$HDR = 3.086\rho_n^2 - 31.872\rho_n + 63.362$	0.967	247.565	0.00
ρ_d	Quadratic	$HDR = -8.043\rho_d^2 + 16.701\rho_d + 10.347$	0.987	625.266	0.00
n	Quadratic	$HDR = -1.742n^2 + 8.229n + 4.4072$	0.946	149.304	0.00
w_a	Quadratic	$HDR = -4.864E - 5w_a^2 + 1.123w_a + 0.371$	0.975	336.020	0.00
I_d	Quadratic	$HDR = -87.163I_d^2 + 89.722$	0.887	140.595	0.00
SHR	Quadratic	$HDR = -0.004SHR^2 + 0.283SHR + 4.39$	0.974	320.641	0.00
V_p	Quadratic	$HDR = 6.967E - 6V_p^2 - 0.064V_p + 147.738$	0.978	384.183	0.00
LAA	Quadratic	$HDR = -0.004LAA^2 + 0.498LAA - 7.868$	0.976	347.486	0.00
PLI	Quadratic	$HDR = 0.098PLI^2 - 2.147PLI + 10.136$	0.936	123.796	0.00
UCS	Quadratic	$HDR = 0.001UCS^2 - 0.178UCS + 10.061$	0.927	107.440	0.00
ν	Quadratic	$HDR = 84.8041\nu^2 - 22.561\nu + 3.713$	0.941	134.782	0.00
E	Exponential	$HDR = 16.358e^{-0.05E}$	0.940	281.791	0.00

4.5. Verification analysis

In order to validate and prove the superiority of this study outputs, the achieved results were compared with the results of the previous studies [3, 6, 8, 9, 12, 18, 19, 22] based on the measured data. For this, four datasets were applied. It should be noted that these datasets weren't used in the development of the suggested relations between HDR and rock properties. Based on these measured datasets, the HDR values were firstly calculated from the suggested relations in this study and other comparable literatures. Then the error of HDR estimations for all of the under-comparison studies were calculated. In the next step, the mean relative error (MRE) of each considered study was calculated in the form of percent. Definitely, a relation with fewer MRE is better than the other comparable ones. In addition to this comparison, the values of upper and lower limits of R^2 index were also calculated for all optimal suggested relations from this study, and compared with the obtained related values of the prior comparable studies. Certainly, the obtained R^2 of the HDR relationships with rock properties (Table 5) were compared with the R^2 values achieved from prior studies. Generally, R^2 index was utilized as an effective technique to evaluate the performance of an equation or a model. An equation with higher R^2 is more accurate, and can predict the precise values of a defined output variable. The results of these comparative analyses based on the four measured datasets and using the MRE and R^2 indices are shown in Figure 18. The given results in Table 6 prove that there is a similar trend in the type of acquired relations from the comparable studies. Therefore, it is confirmed that there is a good agreement between the general results of the current research and previous studies. However, it is confirmed from Table 6 and Figure 18 that the obtained R^2 values from the current research work are higher than the archived R^2 values from the previous studies. In addition, the resulted MREs from this research work are lower than the obtained MREs from the previous studies. This comparison proved that the results of this study are more precise than the similar previous studies in HDR estimations based on the different rock properties. Besides the above quantitative verification, another superiority of this study is that all the possible rock properties are simultaneously considered to estimate HDR unlike the previous studies.

Considering the above verifications, it is confirmed that the proposed equations in this study are the relatively realistic relations to estimate HDR based on the rock properties. As a result, they can be used in the drilling operations of the mining industry, particularly in marble quarries with similar rock properties. However, further studies are required in this field, especially in the evaluation of the effect of rock diversity on the HDR. For this purpose, research examination in different mines besides marble quarry mines is required.

Table 6. Comparative analysis results based on the R^2 and MRE indices.

Considered input parameters	Obtained optimum relation types	Lower and upper limits of achieved R^2	Mean relative error (*MRE*)	Reference
UCS, BTS, PLI, V_p, ρ_n, *ISI, SHR,* and *E* versus *PR*	Linear	0.36-0.9409	33.24%	[6]
UCS, TS, and *PLI* versus *PR*	Linear	0.6292-0.953	28.12%	[8]
UCS, PLI, BTS, SHR, and *SH* versus *DRI*	Linear	0.55-0.78	39.54%	[9]
UCS, TS, V_p, V_s, E_{dyn}, *RDi,* and *SHR* versus *DR*	Linear, logarithmic and exponential	0.4411-0.915	30.41%	[12]
BI versus *PR*	Power	0.699-0.914	No data on BI	[18]
UCS, PLI, BTS, SHR, e, and *n* versus *DRI*	Linear	0.67-0.84	36.97%	[19]
ρ_n, *SH, UCS* and *TS* versus *DRI*	Quadratic and Linear	0.42-0.94	32.56%	[3]
UCS and *TS* versus *PR*	Linear	0.5984-0.9576	51.09%	[22]
ρ_n, ρ_d, *n*, w_a, I_d, *SHR,* V_p, *LAA, PLI, UCS, E,* and *v* versus *HDR*	Quadratic and exponential	0.887-0.963	8.04%	Current research

ISI is the impact strength index, *TS* is the tensile strength, *BTS* is the Brazilian tensile strength, *PR* is the penetration rate, *BI* the is brittleness index, *DRI* is the drilling rate index, *DRi* is the rock mass drillability index, *SH* is the Shore hardness, V_s is the shear wave velocity, *e* is the void ratio, and E_{dyn} is the dynamic Young's modulus. Other variables were explained before.

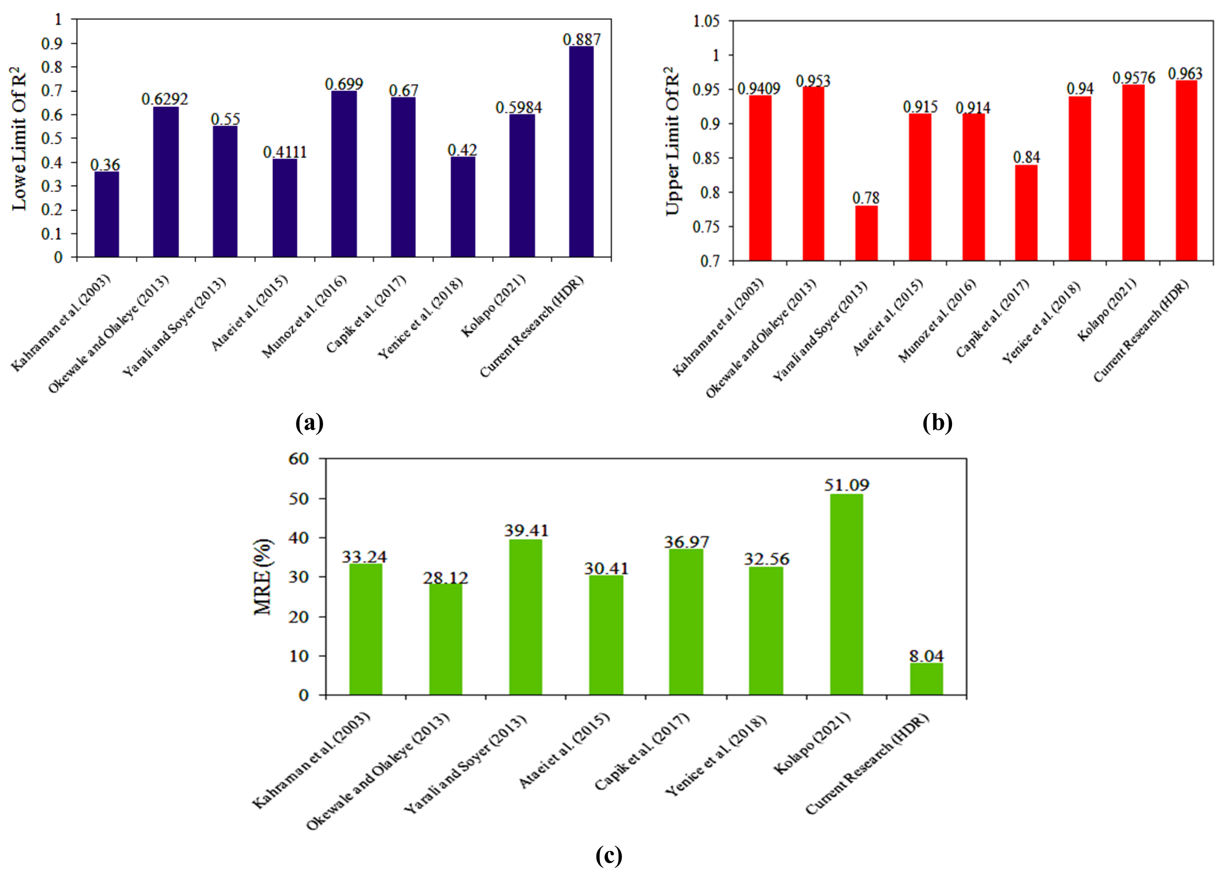

Figure 18. Comparative analysis results: a) Lower limit of R^2, b) Upper limit of R^2 c) MRE.

5. Conclusions

The influence of rock properties on HDR was investigated in the current research work. For this aim, HDR was calculated in the drilling operations of the Malawi marble quarry mine based on the drilling time and length measurements. Then core cylindrical specimens were provided from the collected minor blocks associated to under-drilling mine's major blocks, and the required laboratory experiments were performed. Accordingly, the parametric study proved that HDR had an inverse relation with the ρ_n, ρ_d, I_d, SHR, V_p, PLI, UCS, and E variables. On the contrary, it has a direct relation with n, w_a, LAA, and ν parameters. Generally, it was confirmed that HDR was more correlated to the physical properties of rock than the rock's mechanical characteristics. Also multiple SA confirmed that n and SHR were the most effective variables, whereas ρ_d and ρ_n were the least effective parameters on HDR. Moreover, MRA model with a high value of R^2 (0 0.998) and low error (0.1273) was suggested to estimate HDR based on the 12 rock properties. Furthermore, ANOVA outputs proved that polynomial and exponential equation types were the optimum relations for HDR determining. Finally, comparative analysis proved that there was a close trend and good agreements between the outputs of this research work with the previous studies according to the suggested equations type. However, comparative analysis based on the measured datasets and using the R^2 and MRE criteria verified the results of this research work, and proved that it was more accurate than the previous studies. According to these obtained findings, it could be deduced that this study's outputs were reliable and should be used for HDR determining in practice. Nonetheless, further investigations will be required to estimate the influence of other rock types on HDR.

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ارزیابی تأثیر خواص سنگ بر نرخ حفاری افقی در معدنکاری سنگ مرمریت: مطالعات میدانی و آزمایشگاهی

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چکیده:

حفاری سنگ یکی از مهم‌ترین فرآیندهای عملیات معدنکاری بوده که مستلزم صرف هزینه زیادی است. شناخت کافی از شرایط حفاری و خواص توده سنگ به انتخاب بهینه سیستم حفاری، تعیین دقیق نوع و تعداد لوازم حفاری و پیش‌بینی دقیق نرخ حفاری کمک می‌نماید. فرآیند فوق منجر به افزایش بازدهی حفاری و بهره‌وری معدن می‌شود. در این تحقیق، ارتباط خصوصیات فیزیکی و مکانیکی سنگ با نرخ حفاری افقی مورد بررسی قرار گرفته است. بدین منظور، ابتدا نرخ حفاری افقی در طی فرآیند حفاری در معدن سنگ مرمریت ملاوی، اسلام آباد غرب، ایران اندازه‌گیری شد. سپس، نمونه‌های مغزه‌ای از بلوک‌های سنگی کوچک معرف برای انجام آزمایش‌های آزمایشگاهی و ارزیابی تأثیر خواص سنگ بر نرخ حفاری افقی تهیه گردید. نتایج آزمایشگاهی نشان داد که چگالی طبیعی، چگالی خشک، شاخص دوام، چکش اشمیت، سرعت موج طولی، شاخص بار نقطه‌ای، مقاومت فشاری تک محوره و مدول الاستیسیته دارای رابطه عکس با نرخ حفاری هستند. بالعکس، نرخ حفاری افقی دارای رابطه مستقیم با تخلخل، آب محتوی، سایش لس‌آنجلس و ضریب پواسون است. به‌طور کلی، اثبات گردید که وابستگی نرخ حفاری افقی به خواص فیزیکی سنگ بیشتر از خوص مکانیکی است. همچنین، آنالیز حساسیت نشان داد که متغیرهای تخلخل و چگالی خشک سنگ به‌ترتیب بیشترین و کمترین تأثیر را بر نرخ حفاری افقی دارند. بعلاوه، معادلات تجربی بهینه جدیدی با دقت قابل قبول برای پیش‌بینی نرخ حفاری افقی بر اساس مدل‌سازی آماری پیشنهاد شد. در نهایت، تحلیل اعتبارسنجی آزمایشگاهی برتری این مطالعه را نسبت به مطالعات قبلی مشابه اثبات نمود.

کلمات کلیدی: معدن سنگ مرمریت، نرخ حفاری افقی، خواص فیزیکی، خواص مکانیکی، مدل‌سازی آماری.