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# Application of Rock Engineering System (RES) Approach in Evaluating Geomechanical Parameters of Rock on Drilling Penetration Rate in One of the Fields of South of Iraq

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## Abstract

Drilling is an important and expensive operation necessary for the exploration and exploitation of oil resources. One of the important goals of drilling operations is to achieve higher drilling speeds at a lower cost while maintaining safety. In drilling operations, the time and efficiency of the operation are of great importance as factors that are directly related to drilling costs. One of the criteria for the efficiency of drilling operations is the penetration rate of the drilling rig. Estimating this parameter and knowing it when planning to drill a well can help to more accurately assess the drilling time and estimate its cost. Also, a reasonable knowledge of the physical and mechanical properties of the rock and the proper selection of drilling operation parameters will help a lot in reducing drilling and production costs. In this study, in order to investigate the factors affecting the penetration rate, the most important effective factors were two categories of controllable (operational) and uncontrollable (environmental) factors. Obtaining a model that can find the relationship between these factors and the penetration rate has always been of particular importance. However, the mathematical modes presented in this regard have focused more on controllable and operational factors. The complexity of the drill-rock interaction as well as the combined effect of the factors affecting the penetration rate has made that conventional methods are not able to fully analyze and predict the penetration rate. The main reason for this can be related to the numerous factors affecting the penetration rate and on the other hand the interaction between these factors. To overcome this problem, the Rock engineering systems (RES) approach has been used. In order to investigate the effect of factors affecting the infiltration rate, the information of one of the wells in Majnoon oil field has been used. In this regard, first the factors affecting the penetration rate are identified and then using the approach of Rock engineering systems (RES) an index called the penetration index (PI) is predicted. The results show that in the study area, depths of 2728 and 3574 meters have the highest and lowest penetration indices, respectively. Also, among the factors affecting the penetration rate, the porosity factor was recognized as the most influential factor on the penetration rate.

Keywords: Drilling penetration rate, operational factors, environmental factors, Rock engineering systems

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## Introduction

Drilling plays an important role in oil and gas exploration and extraction. Due to the high costs of drilling operations, forecasting the drilling time and creating a schedule for this process can effectively increase the efficiency of the operation and reduce the costs associated with them. Since the drilling process has a special place in the upstream oil industry and can be called as one of the most costly upstream activities, so paying more attention to this issue can study the problems and difficulties facing this Industry is important. Undoubtedly, many factors in the performance of drilling rigs, including technical, economic and political factors can have a great impact in this regard. Missed times and times associated with displacement are essential parameters in the efficiency of drilling rigs. The concept of time for each drilling operation can be expressed by the penetration rate. Many factors affect the penetration rate that if a relationship is found between these factors and the penetration rate, a model can be achieved to optimize drilling operations[1].

## Drilling penetration rate

Drilling penetration rate is the rate of drilling progress in rocks and formations under drilling per unit time. This parameter is known as feet per minute or meters per hour. The penetration rate of the drill bit along with the wear rate of the drill are two factors that have a definite and direct effect on the drilling costs per foot. Measuring the penetration rate in the drilling industry is very important and helps the driller in cases such as examining how the drills work (eg wear and fracture of drill teeth) and optimizing controllable drilling factors (drill load and rotation speed). he does . This index is measured and recorded by monitoring drilling and well drilling operations. In general, the penetration rate is examined in both instantaneous and average forms[2]. Instantaneous penetration rates are recorded over a limited period of time and in fact only during drilling. According to the evaluation of this amount, drilling in each specific formation and the impact of drilling parameters on drilling operations can be described. Another type of calculated infiltration rate, known as the average infiltration rate, is calculated during the drilling period and the interval between the drilling pipe equipment entering the well until its return. However, today, due to advances in well drilling and drilling monitoring technologies, electronic tools and sensors are used for measurement [3].

## Drill penetration rate factors

Drill penetration rate in drilling industry is usually obtained from interfaces based on drilling area in terms of time, the amount of which is strongly influenced by many factors, which are as follows:

### 1- Type of field

The amount of drilling penetration rate according to the type of exploration or development field and sea or land (Figure 1) have different values so that in exploration fields due to lack of necessary information and insufficient knowledge of the geological

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situation and the possibility of high pressure zones can be Expected high drilling rate penetration rate, but in development fields, unlike exploration fields, due to the necessary information on the status of the reservoir and geology of the area (by information obtained from neighboring wells) can be high drilling rate with special arrangements in the drilling program. Expected[4].

Figure 1: Type of offshore and onshore rigs

**2- Type and power of drilling machine**

Since drilling rigs are usually classified into two types of land-sea and repair-drilling, they have their own power and strength in proportion to it, so that some of them have capabilities of 1000, 1500, 2000 and 3000 horsepower, which according to their power, different drill penetration rates are obtained from them[5].

**3- Type of drill and material of construction**

The choice of drill type is selected according to the material and depth of the formation, which is one of the main factors determining the amount of drilling penetration rate, because in case of incorrect selection of drill type, in addition to damage to the drill and the formation, the appropriate drilling penetration rate can no longer be Expected[6].

**4- Depth of formation**

The depth of the formation is another factor that can have a great effect on the drilling speed. Potential high pressures, rock cover layer and reservoir layer as well as temperature increase of drilling speed naturally decrease and the amount of drilling penetration rate may be significantly reduced[7].

**5- Type and pressure of drilling mud**

The choice of this factor, considering the depth of drilling and providing the necessary pressure in the well, can have a great effect on the penetration of the drill hole. And

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reduce the drilling speed, so the correct choice of this factor should be carefully considered in the drilling program (Figure 2).

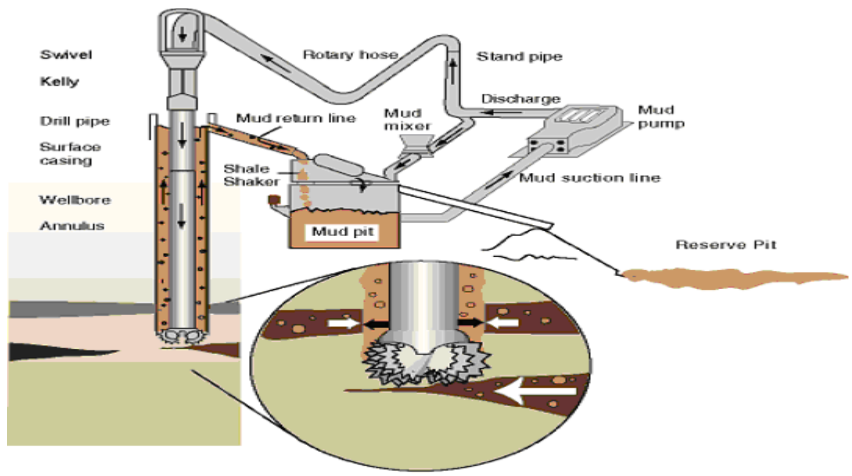


Figure 2: View of mud flow in oil and gas wells

According to the above, it is clear that finding the right drill penetration rate depends on many parameters, so the correct choice of this type of parameters in the drilling program is inevitable and can increase the drill penetration rate and should also be considered. It should be noted that increasing the drilling penetration rate should be calculated and reasonable because in some cases its unprincipled increase can cause the reservoir rock to break and eventually waste drilling mud[8].

In the meantime, according to the type of information received and also the importance of the formation, the amount of drilling penetration rate of the rigs has been divided according to the type of formation. Figures 3 and 4 show Penetration rate versus hole length.and the drilling penetration rate of each drilling rig, respectively [8].

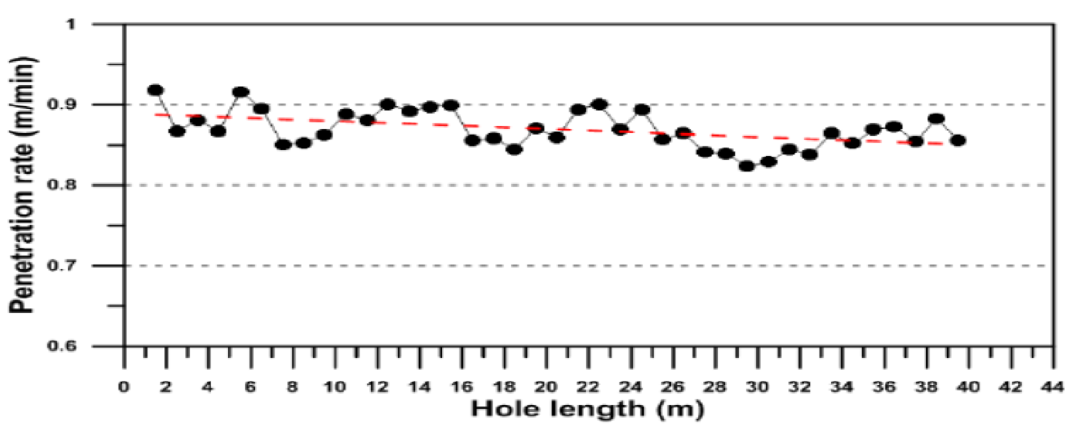


Figure 3: Penetration rate versus hole length.

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It is worth mentioning that the average penetration rate of the total drilling of some active rigs, both onshore and offshore, in different formations is calculated to be about 37 meters per day, which can be due to the above points and timely and correct supply of goods and Materials should be increased to optimal amounts of 45 to 50 meters per day[9].

**Majnoon Square**

Majnoon oilfield is located in southern Iraq, Basrah and Missan Governorate, 65 km to the north west of Basra City, close to the Iraqi Iranian borders .

This oil field was discovered after interpretation of the seismic survey data which was done by Petro Brass (Brazilian Company) in 1972. The first exploration well was drilled in 1976. The length of structure is approximately 50Km, while its width is approximately 11Km. It covers a surface of approximately 400 $Km^2$. The area of Majnoon Oil Field lies within Zubair subzone of Mesopotamian zone as in Figure 4[10]:


*Figure 4: Location of Majnoon oil field in Mesopotamian*

The Cretaceous sediments of the Mesopotamian Basin are one of the richest petroleum systems in the world. These are overlain by multiple, tight carbonate and shale seals. Potential

is estimated to contain up to 38 billion barrels of oil resources including an estimated recoverable reserve of more than 12 billion barrels.

Although discovered and undertaken for development in the 1970s, the oil field project suffered long delays due to the Iraq-Iran conflict.

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International oil companies, Shell and Petronas, were offered to redevelop the field to raise its production up from 45,000 barrels of oil per day (bopd) to a plateau production level of 1.8 million barrels a day , under a contract awarded in 2010[11].

After restarting production in 2013 and operating barely for four years, Shell and Petronas, however, decided to exit the Majnoon concession, in anticipation of a steep decline in profitability following a decline in oil prices.

New production wells were drilled and a central processing facility (CPF) was constructed, apart from revamping the existing installations for the field.

First oil from the redeveloped field was attained in September 2013 with an initial production capacity of 175,000bopd, which was enlarged to 194,000bopd in 2014. Shell and Petronas left the field in 2018. The output was promote increased to 210,000bopd, before that. The onshore field spans 52km-long and 15km-wide and comprises 13 oil and gas reservoirs of the Cretaceous age.

**Position of the desired well**

The studied well with latitude and longitude 31.042956, 47.632767 is located in the south square of Majnoon oil field. With an area of about 366 square kilometers, this field is part of the **Azadegan** oil field, which is located in the border area between Iraq and Iran in southeastern Iraq[11].

**Rock Engineering System (RES)**

The Rock Engineering Systems were first introduced by Hudson in 1440 and have been widely used in solving engineering problems ever since.

The Rock engineering system (RES) method was proposed by researchers in 1992 because there is insufficient information between all the necessary variables and their interaction.

In most of the previous applications of this approach of Rock engineering systems (RES), in the part of determining the interaction of parameters, the traditional method of coding the interaction matrix has been used, which is not able to describe the interactions correctly and has a completely subjective and estimative aspect. Efforts have also been made to improve the approach and integrate it with other theories that have not been significantly used in practice[12].

In the systems approach, interaction matrices are powerful tools that measure the interaction of parameters affecting each other on an equal scale. In the interaction matrix, the effective parameters are placed on the main diameter of the matrix, and the interaction of the parameters with each other according to it is determined by coding in the non-diagonal elements of the matrix. The interaction matrix is used to identify critical parameters, effective paths, return loops, and evaluate selected engineering techniques. In interaction matrices, the main parameters are placed in the main diameter of the matrix[12].

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In this way, the system can be defined as consisting of effective components with a boundary. Thus, the whole can be defined as the system response resulting from the interactions of all components (rather than the simple sum of those components).

**Rock Engineering System (RES) approach**

In designing geotechnical projects, it must be ensured that all the influencing factors and the interactions between them are taken into account. As a systematic method for dealing with all interactions, they can be located in a matrix. This work is used as a basic tool by the Rock engineering systems (RES) approach. The main factors related to the problem are located along the main diameter of the matrix and the interactions of each pair of factors are formed in other components. Steps such as coding interactions and algebraic operations are applied to rows and columns, and the method continues with the output of graphs[13].

The common method in presenting and showing interactions in systems is to use interaction matrices. In these matrices, the main factors are placed along the main diameter of the matrix. As shown in Figure 7, factor A is in the upper left corner and factor B is in the lower right corner of the matrix.

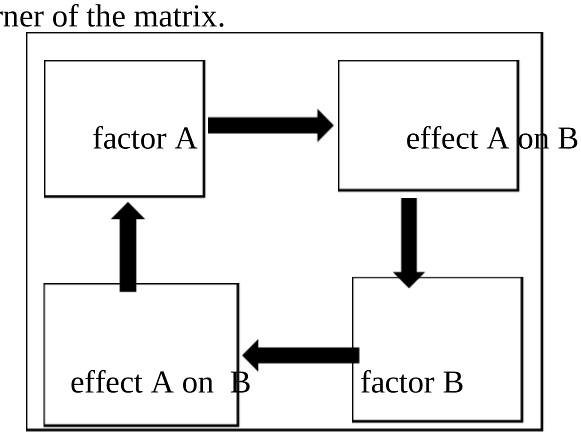


Figure 5: The concept of interaction matrix for a system consisting of two factors A and B.

The upper right represents the effect of A on B and the lower left indicates the effect of B on A. Thus, in fact, the basic principles of the interaction matrix are the location of the main factors along the original diameter and the consideration of the interactions in the non-principal diameters[14].

**Interaction matrix coding**

After the interaction matrix is constructed, the relationship between the factors affecting the problem in terms of quality and analysis can be observed simultaneously in this matrix and compared with each other. But this form of comparison is qualitative and time consuming, and people usually make different judgments of a relationship, so it is necessary to quantify these relationships, which is described below[15].

### Cause and effect diagram

The principal factors (Pi) are listed along the principal diameter of the matrix. Depending on how the matrix is constructed, it is necessary that each row passing through Pi indicates its effect on all other factors in the system, and vice versa, each column passing through Pj indicates the effect of other system factors on that factor. Once the matrix is numerically encoded, the algebraic sum of the values of each row and each column can be obtained, the sum of each row being known as the cause, as well as the sum of the values of each column called the effect, which ultimately causes Axes C and E are formed. Thus, C represents how Pi affects the system, and E represents the effect that the system has on Pi. The values of the axes for each parameter can be displayed on the cause-effect diagram[15].

## Results

The combined effect of all the studied factors and also the different degree of importance of each of them in the drilling speed, makes the problem of drilling and optimization very difficult and complicated. Thus, different solution methods have always been proposed by experts to determine the relationship between factors. Rock engineering method (RES) is one of the most common methods of solving linear and nonlinear problems that has been used extensively in modeling various problems. In the present study, this method is used to determine the relationship between existing factors. For this purpose, in this chapter, the expert semi-numerical coding (ESQ) method has been used to apply the RES method. First, the interaction matrix was coded by ESQ method and then the weight of each factor was obtained by the relations described in the second chapter, and then the penetration index at four different well depths was calculated. Finally, the factors that affect the penetration rate are analyzed for depths with low penetration index.

### Factor interaction analysis using the RES approach

In this section, the interaction between factors is calculated by the mean interaction matrix and then the mean weight of each factor is calculated by the interaction matrix.

### 1- Mean interaction matrix

The mean interaction matrix (MIM) consists of the average scores given by drilling connoisseurs to the interaction of factors influencing the penetration rate. In constructing this matrix, the opinions of 10 experts from university and industry professors have been used[15].

### 2- Coding the interaction matrix

In this section, the ESQ coding method is used, with the difference that instead of using one person's opinion, the average of 10 people's opinions is used and the term "average interaction matrix" (MIM) is used.

In order to form the interaction matrix, in addition to the 11 factors influencing the penetration rate, the twelfth factor, ie the penetration rate, is also included in the main diameter of the matrix. As a result, the average interaction matrix has 12 rows and 12 columns, and the main diameter of the matrix contains the 12 factors mentioned. The interactive column that passes through the last layer shows how operational and geomechanical factors affect the penetration rate. Similarly, the line passing through this knowledge indicates the effect of the penetration rate on the system. The sum of all row codes is calculated as the cause of C and the sum of all column codes is calculated as the effect of E for each parameter. The mean interaction matrix is shown in Table 1[16].

Table 1: Mean interaction matrix

| | | | | | | | | | | | | | ΣC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **P1** | 2.2 | 0.3 | 0 | 0 | 0 | 0 | 0 | 0 | 1.3 | 0.3 | 3.8 | 7.9 |
| | 1.3 | **P2** | 0.2 | 0.3 | 0 | 0 | 0 | 0 | 0 | 1.5 | 0 | 3.9 | 7.2 |
| | 1.6 | 1.1 | **P3** | 2.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.1 | 7.1 |
| | 1.2 | 1.4 | 1.3 | **P4** | 0 | 0.2 | 0.1 | 0.1 | 0 | 0.6 | 0 | 2.9 | 7.8 |
| | 1.9 | 2.2 | 1.5 | 1.4 | **P5** | 2.1 | 2.1 | 2.3 | 2.2 | 1.8 | 2.4 | 2.8 | 22.7 |
| | 2.1 | 2.3 | 1.3 | 2 | 3.1 | **P6** | 3.3 | 3 | 2.4 | 1.9 | 2.8 | 3.4 | 27.6 |
| | 2.6 | 2 | 0.8 | 1.3 | 1.8 | 1.3 | **P7** | 3.3 | 2.4 | 2 | 2.5 | 3.3 | 23.3 |
| | 2.2 | 2.1 | 0.7 | 0.5 | 1.4 | 1.2 | 3.1 | **P8** | 2 | 1.8 | 2 | 3.1 | 20.1 |
| | 1.7 | 2.6 | 0.5 | 0.3 | 1.2 | 1.1 | 2.2 | 2.3 | **P9** | 3.1 | 2.1 | 3.4 | 20.6 |
| | 1.5 | 2.6 | 0.7 | 0.5 | 0.8 | 0.8 | 1.4 | 1.2 | 2.1 | **P10** | 1.1 | 3.2 | 15.9 |
| | 2 | 2.1 | 0.3 | 0.9 | 1.3 | 1.6 | 2 | 1.7 | 1.5 | 1.1 | **P11** | 2.8 | 17.3 |
| | 1.1 | 0.9 | 0.6 | 0.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **P12** | 3.4 |
| **ΣE** | 19.2 | 21.5 | 8.2 | 10.3 | 9.6 | 8.3 | 14.2 | 13.9 | 12.6 | 15.1 | 13.3 | 34.7 | |
| P1: load on the drill; P2: drill rotation speed; P3: mud weight; P4: fluid flow rate; P5: rock density; P6: porosity; P7: uniaxial compressive strength; P8: tensile strength; P9: Rock hardness; P10: rock stiffness ; P11: Young module; P12: Penetration rate C: Cause, E: Effect | | | | | | | | | | | | | |
| Operational factors | | | | Geomechanical factors | | | | | Penetration rate | | | | |

### 3- Intensity of interaction

From the interaction matrix, a lot of information is obtained, including the degree of impact, effectiveness and the degree of participation (intensity of interaction) of each

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factor in the problem. As shown in Figure 6, the effect of uniaxial porosity and compressive strength on the problem (penetration rate) is much higher than other factors; In other words, these two factors will be the most important factors that change the penetration rate during drilling[17].

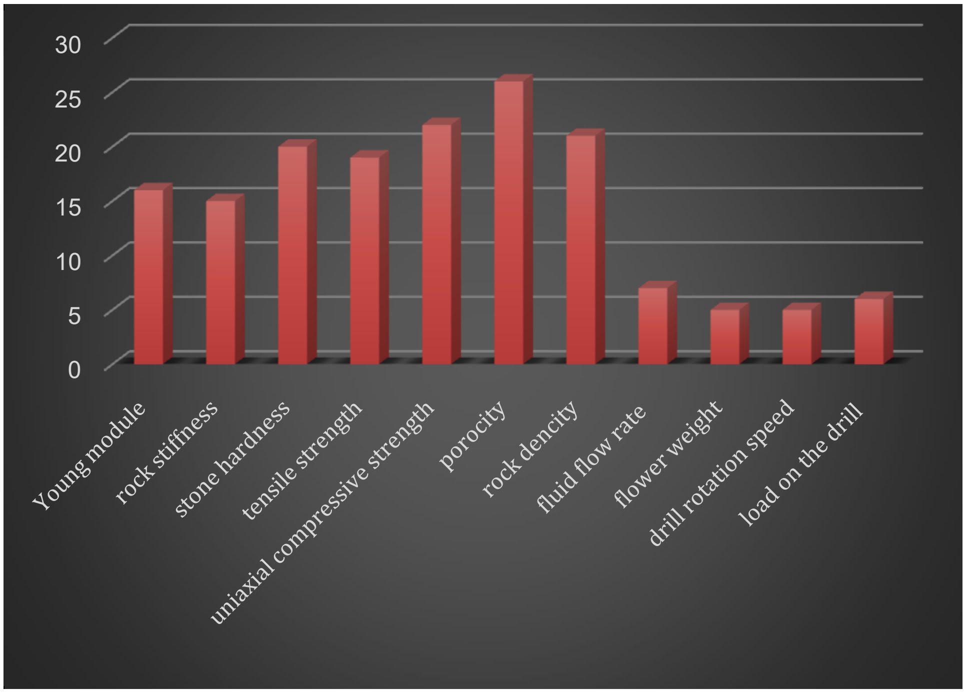


Figure 6: The extent to which factors affect the penetration rate

Also, it can be seen from Figure 7 that the effect of drill speed and load on the drill of the problem in question was higher than other factors. This means that in order to increase the penetration rate, more attention should be paid to these two factors.

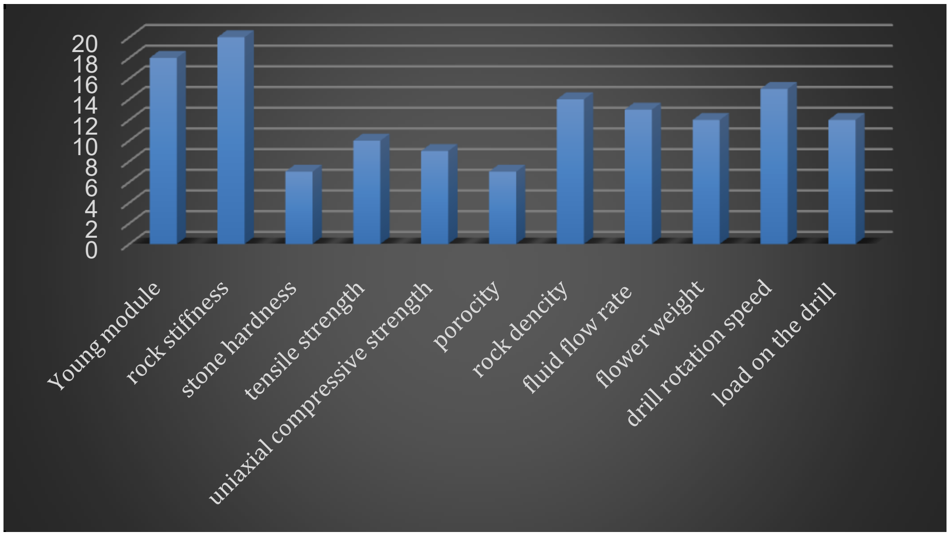


Figure 7: Influence of influencing factors on penetration rate

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From the total effect and effectiveness (C + E) of a factor, the intensity of the interaction of that factor is obtained, which indicates the importance of that factor. Figure 8 shows that the intensity of the interaction between uniaxial compressive strength and porosity is higher than other factors.

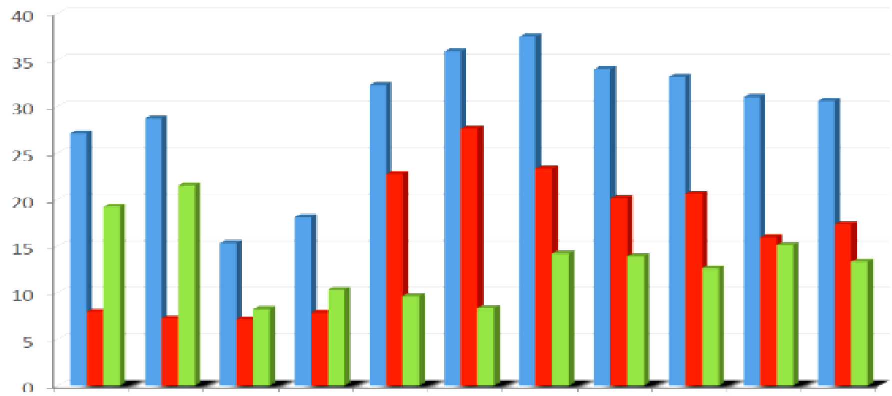


Figure 8: Intensity of factors affecting the penetration rate

So that the change of organs in them has a great impact on the system. Cause-effect diagram shows the degree of dominance or defeat of a factor in the system. The line C = E determines whether each factor is dominant or defeated. As shown in Figure 9.

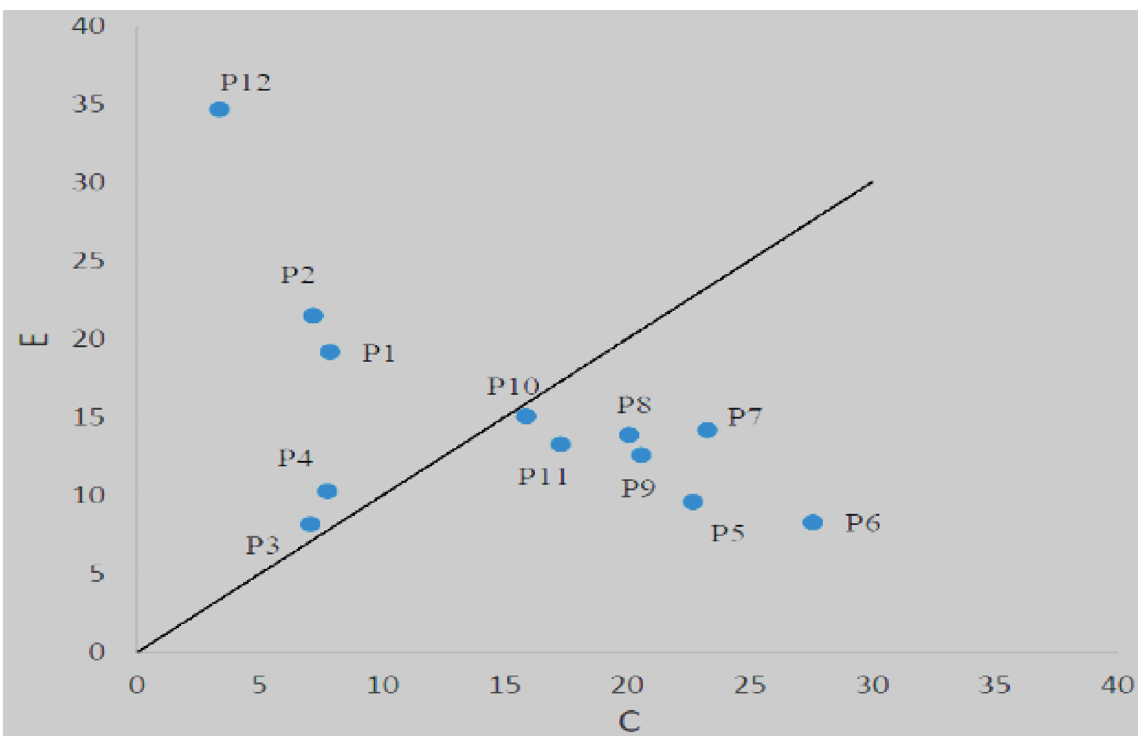


Figure 9: Cause-effect diagram of factors

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The more a factor is inclined from the line C = E to the axis of the cause (C), the more dominant that factor is and the more it affects the problem. It is more defeated and more effective than the problem. As a result, according to Figure (12), it can be said that in addition to the penetration rate, which is completely affected by the system, geomechanical factors are the most effective and operational factors are the most affected by the problem.

**4- Determining the weight of the factors affecting the problem**

The intensity of interaction of each factor in the approach of Rock engineering systems is the sum of cause and effect (C + E) of that factor. The intensity of interaction of each factor indicates the importance of this factor in the system under study. As a result, according to Equation 1, the percentage of the intensity of the interaction of the factors is considered as their weight coefficient in the problem.

$$a_i = \frac{(C_i+E_i)}{\left(\sum_i C_i+\sum_i E_i\right)} (\%) \qquad \ldots\ldots\ldots\ldots\ldots\ldots \text{Eq(1)}$$

In this regard, Ci and Ei are the cause and effect of factor i and i are the counter of the agent, respectively. Obviously the value of ai will be a number between zero and one.

Estimation of penetration index.

After determining the weight of each factor, the infiltration index (PI) for four different well depths is estimated. The penetration index at each depth indicates the rate of penetration rate for the desired depth. In other words, the more favorable the conditions for drilling at the desired depth, the higher the value of the penetration index at that depth. The value of the penetration index for each depth is calculated using Equation 2.

$$PI = \sum_{i=1}^{n} a_i \frac{P_i}{P_{max}} \qquad \ldots\ldots \text{Eq (2)}$$

αi The weight of the factor ai and Pi is the value (score) of the factor at that depth and the Pmax is the maximum value that a factor can have (single factor). For comparison, Table 2 shows the results of the infiltration index obtained from the RES method and the actual infiltration rate measured in the well.

Table 2: PI index usability assessment (validation)

| rate penetration actual (m / h) | PI value calculated | Depth (m) |
|---|---|---|
| 8/52 | 59/81 | 2728 |
| 6/22 | 38/45 | 3113 |
| 6/46 | 36/26 | 3371 |
| 3/72 | 22/70 | 3574 |

The results indicate that the predictions made by the RES method at depths of 2728, 3113 and 3574 meters are completely consistent with field observations. But by comparing at a depth of 3371 meters, it was found that the value of the penetration index obtained with the actual value at this depth is slightly different, which can be due to the angle of internal friction at the bottom of the rock due to low resistance at a depth of 3371 meters

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in the field. Be desired. This suggests that more accurate parameters of the rock need to be considered for more accurate estimation. This requires more information so that their impact can be considered in the interaction matrix. It should also be noted that the values of the penetration index obtained from the RES method are relative values[18].

## Conclusion

So far, many researches have been done on the effect of operating factors on the penetration rate, but insufficient attention has always been felt to the effect of the mechanical properties of the rock in this research. Due to the great importance of the penetration rate in the drilling industry, in this study, an attempt has been made to identify the effect of the effective factors on the drilling penetration rate with a special look at the geomechanical properties. The case study intended for this research is one of the wells in Majnoon field. Then the penetration index in the four well depths was calculated separately.

In order to predict the penetration rate, it is necessary to identify the factors affecting drilling. In the present study, in order to estimate the penetration index, the effective factors were divided into two categories: operational and geomechanical factors. First, the mean interaction matrix was analyzed and the weight of the factors affecting the penetration rate was calculated, and then the penetration index was calculated by the Rock engineering system method for four depths. Accordingly, the depths of 2728 and 3574 meters have the highest and lowest penetration indices, respectively. Finally, the values of the penetration index obtained from the RES method were compared with the values of the actual penetration rate at four different depths of the well. The results showed that except in one case, the PI predictions are fully consistent with the field observations, which confirms the capability of the proposed method.

The results of the present study include the following:

• In this study, 11 factors affecting the penetration rate have been evaluated. The weight of these factors has been calculated in general and is not specific to the present study. Therefore, the results of this research can be used in similar cases.

• Among the factors affecting the penetration rate, porosity and drilling mud weight have the most and the least effect on the penetration rate, respectively. Due to the porosity of the environment and high impact on other properties of porosity rock was recognized as a very important factor in this well. Also, the factor of drill rotation speed and drilling mud weight have the most and the least impact of the problem, respectively. As a result, with the drill speed control factor, the desired penetration rate during drilling can be achieved to a large extent.

• Depths of 2728 and 3574 meters obtained the highest and lowest penetration indices, respectively. It can be concluded that with increasing depth, the infiltration rate decreased and considering that the values of operational factors in the four depths of the well had a small range of changes, so the impact of geomechanical factors on the infiltration rate at greater depths is more felt.

• Due to the factors that have a greater impact on the penetration rate, it is possible to control the operational factors in the depth with low penetration rate and create more ideal and suitable conditions due to the high cost of drilling oil wells.

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