TRI-CONE BIT SELECTION BASED ON GEOMECHANICAL PARAMETERS USING THE SONIC LOG

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ABSTRACT: *Bit selection is one of the main challenges in deep well drilling operations. Much of the cost per well is related to the drilling phase. On the other hand, development of an optimized drilling operation may be summarized in effective use of bit. Selecting an appropriate bit for specific drilling conditions requires several parametric evaluations. In this research, we established essential characteristics of formation drillability namely uniaxial compressive strength and Mohs hardness based on the petrophysical logs, daily drilling reports and bit records of the offset wells.*
We established an optimized bit selection scheme based on the formation characteristics and classification criteria for drilling bits developed by international association of drilling contractors (IADC). In the next step we could recommend optimum bit selection. This approach led to a cost effective drilling operation and bit program for studied fields.

Key Words: Sonic log, Uniaxial Compressive Strength, Schmidt Hardness, Drillability, Bit Selection, IADC Table.

1. INTRODUCTION

Historically, drilling bits are selected according to performance records in the field and on the basis of the lowest running cost. Often due to lack of familiarity with geomechanical characteristics of drilling formations or lack of information for bit performance, the best bit records are not available. As a result, the optimum bit selection is obtained through trial and error at a considerable extra expense for a great number of wells. Furthermore, in many cases the optimum bit selection procedure is never attempted, whereas if the offset records do not contain lithology or strength information, practical problem will appear. Hence, bit performance over the drilling intervals and bit operating conditions can be inferred from bit records, while information about what a bit has penetrated may be obtained from logs, not from bit records. Accordingly, using log data can significantly ease the economical bit selection scheme.

2. Uniaxial compressive strength and hardness according to acoustic wave velocities

Experimental studies confirm that sonic velocities are correlated with rock hardness, drillability, and strength. Gstalder and Raynal measured rock hardness directly from core samples and then from compressional wave velocities as an alternative method [1]. They concluded that if compressional wave velocities increase, the rock hardness will increase. Also Summerton and Hadidi experimentally measured drilling strength and compressional wave velocities and concluded that if compressional velocities increase the drilling strength will increase [2]. Mason showed in his studies the strong tendency of rock hardness and uniaxial compressive strength to increase with increasing shear wave velocities [3]. From the literature we realize that a very good correlation exists between compressional wave velocities and the rock hardness, as well as the uniaxial compressive strength.

Rocks have a wide variety of physical, mechanical and geological properties, which have direct and indirect impacts on the drilling operation. Some of the physical properties are porosity, density, texture, structure and adherence. Mechanical properties of rock indicate the strength and stiffness of rock against the input force. Some of these parameters are Uniaxial Compressive Strength (UCS), cohesion (c), angle of internal friction (φ), hardness, Young's modulus (E) and Poisson's ration (υ). Meanwhile, geomechanical parameters of the rock formation are necessary for studying drillability and bit selection [4]. Among these parameters, Young's modulus is the most essential. Elastic waves in rock propagate with a velocity that is function of elastic stiffness and density of rock. Equation (1) is proven to accurately define elastic wave propagation in an isotropic solid material. Nevertheless, all these parameters depend on other parameters such as porosity and confining stresses when applied in the field. In this research we used Equation (1) to estimate **E** from wave velocities [5].

$$\mathrm{E} = \frac{\rho Vs^2(3Vp^2 - 4Vs^2)}{(Vp^2 - Vs^2)} \qquad \text{Eq. (1)}$$

Vs (Km/s) = Shear wave velocity
Vp (Km/s) = Compressional wave velocity
ρ (gr/cm^3) = Density
E (GPa) = Elastic modulus

Therefore, rock mechanical properties can be estimated using dipole sonic log providing P-wave and S-wave velocity information and density log. However, very often S-wave velocity is not recorded in the field. Therefore prediction of the S-wave velocity is an interesting objective for researchers .Alternatively, if dipole sonic logs are not available, we may use a prediction equation for estimating shear wave velocity from compressional wave velocity obtained from sonic log. In this paper we used recently developed Equation (2) for estimating shear wave velocity [6].

$$V_S = 1.68 + \frac{1.56}{1 + EXP(-\frac{V_P - 4.46}{0.63})} \qquad \text{Eq. (2)}$$

3. Effective criteria for bit selection

The mission of IADC (International Association of Drilling Contractors) is to improve drilling and completion technology for helping oil companies in their jobs through published classification charts and tables. In this research we use IADC tables which identify bit codes according the rock mechanic parameters. According to these tables UCS and hardness are among important parameters for bit selection as it is explained in the next paragraphs.

3.1 Rock hardness

Hardness of a mineral is measured by fingernail, needle, steel body or quartz in Mohs scale [7]. The Mohs scale of mineral hardness characterizes the scratch resistance of various minerals through the ability of a harder material to scratch a softer material. In drilling operations, however, we need to know the hardness of the rock formation continuously throughout the drilling length. On the other hand, estimation of hardness is very complex. This is because hardness of rock material depends on hardness of rock forming minerals, connection between the minerals and the source rock. For example quartzite as a metamorphic rock characterized by interlocking quartz grains is very hard and according to the Mohs scale its hardness is equal to 7. Nevertheless, calcareous sandstone as sedimentary rock containing a high percentage of quartz mineral is scratched with knife and therefore its harness is less than 7 [8].

As it is clear hardness is determined directly from formation core samples. However, Schmidt hammer rebound number is an alternative method to determine the hardness of formations. According to the literature, finding an appropriate bit code requires a good estimation of rock hardness. So far, several correlations have been suggested to predict rock properties based on Young's modulus. Equation (3) is one of the most appropriate correlations to estimate the Schmidt hammer rebound number (N) in the field [9].

$$N = 0.5155E + 17.488 \qquad \text{Eq. (3)}$$

E (GPa) = Elastic modules

N= Schmidt hammer rebound number

3.2. Uniaxial compressive strength (UCS)

One of the most important parameters in collapse mechanism and rock failure is uniaxial compressive strength of rock. Rock failure can occur in different ways, depending on the type of bit. Mason showed that hardness and uniaxial compressive strength of rock formation depend on the shear wave velocity [3]. Knowing the strength of these rocks is important for bit selection, mud weight design, and well planning. The purpose of strength factor is verification of the maximum compressive stress that rock can suffer under uniaxial loading without failure [10].

For direct measurement of UCS we need well preserved intact core samples. Nevertheless, core sample preparation from oil field formations is very expensive and time consuming. Therefore, we would rather use indirect method to estimate UCS. There are several correlations which relate N to rock properties. In this research we used Equation (4) to estimate UCS from Schmidt hammer rebound (N) and it seems to be more accurate than other similar correlations [11].

$$\text{UCS} = 13.02\, exp(0.0414N) \qquad \text{Eq. (4)}$$

4. Drillability

Drillability is one of the most important properties for any formation classification attempt, bit selection and drilling. Drillability of a formation is affected by lithology and hardness. An outstanding empirical method for predicting drillability is Mohs scale [7]. In this method the drillability of the formations is characterized based upon the hardness and UCS of rock according to Table 1.

5. Geology of the studied oil field

Maroon is one of the largest oil fields in the southwest Iran, located in the northeast of Ahvaz. In fact, it is adjacent to the northeast fields of Koopal, Aghajari, Shadegan and Ramshir. Its length is 67 km and its average width is 7 km. In terms of geologic basins, it is located in the eastern part of fallen branch in the north of Dezful. Maroon oilfield contains different lithologies and encountered very challenging drilling operation in the past. Some of the formations are over pressurized and others are normal to subnormal. Studied formations include Aghajari formation (Miocene –Paleocene age) made up of mainly red marl, minor layers of grey marl, siltstone, and calcareous sandstone as well as Mishan formation (Miocene age) made up of mostly grey marl and limestone.

6. IADC table

Two-digit numbers of the IADC code represent the cutting structure of the tri-cone bit that is important to produce the most economical bit run. This two-digit number is identified based on the formation geomechanical parameters. The third digit of the IADC code identifies the bit bearing/gauge type. The bearing/gauge is playing an important role in maintaining operational reliability and the effectiveness of the bit. Drilling engineers use the offset well bit and daily drilling report for selecting an appropriate gauge protection and/or bearing to avoid failure [8]. IADC table for bit selection is illustrated in Table 2.

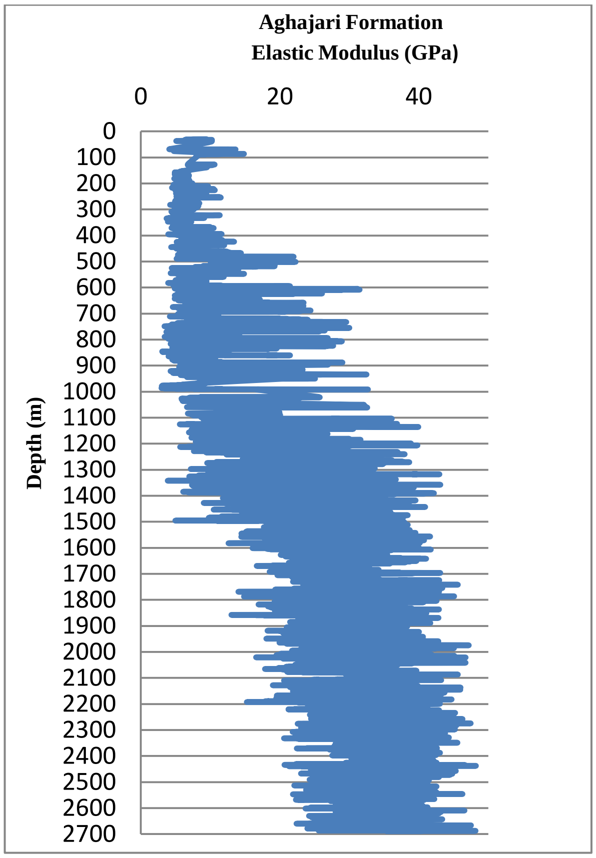

Figure1. Elastic modulus for Aghajari formation

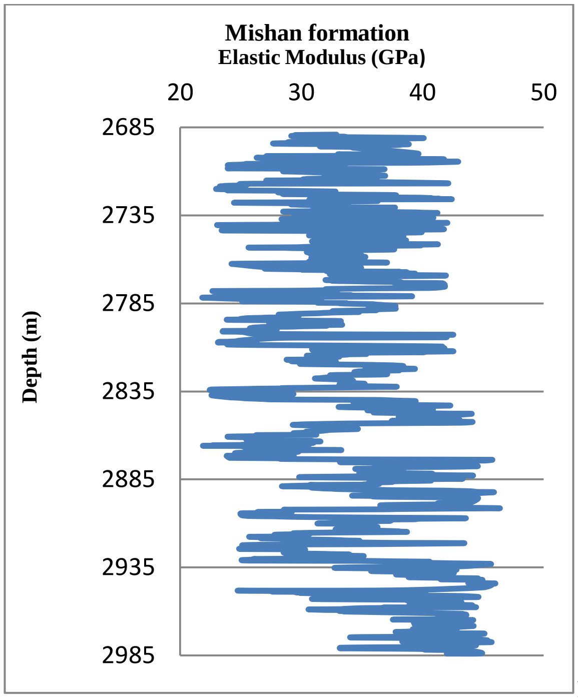

Figure **2. Elastic modulus for Mishan formation**

- Continuous estimation of Schmidt hammer rebound number of the well length (as in Figure 3 and 4)

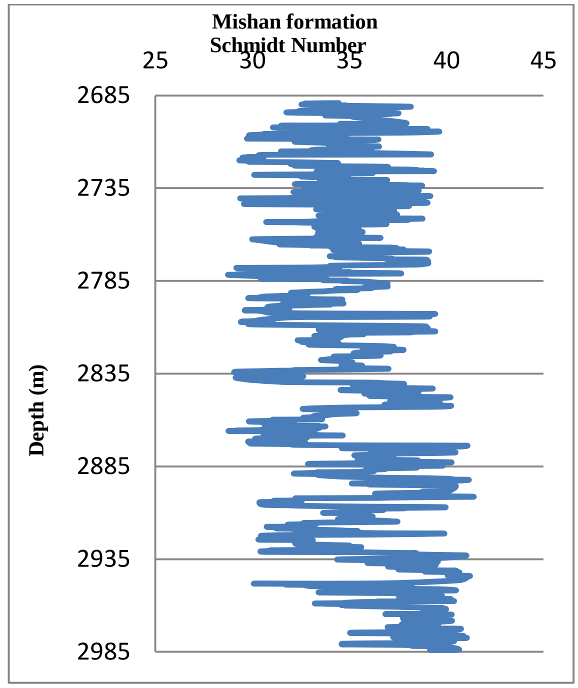

Figure 4. Schmidt rebound number for Mishan formation –

Continuous estimation of UCS value of the well length (as in Figure 5 and 6)

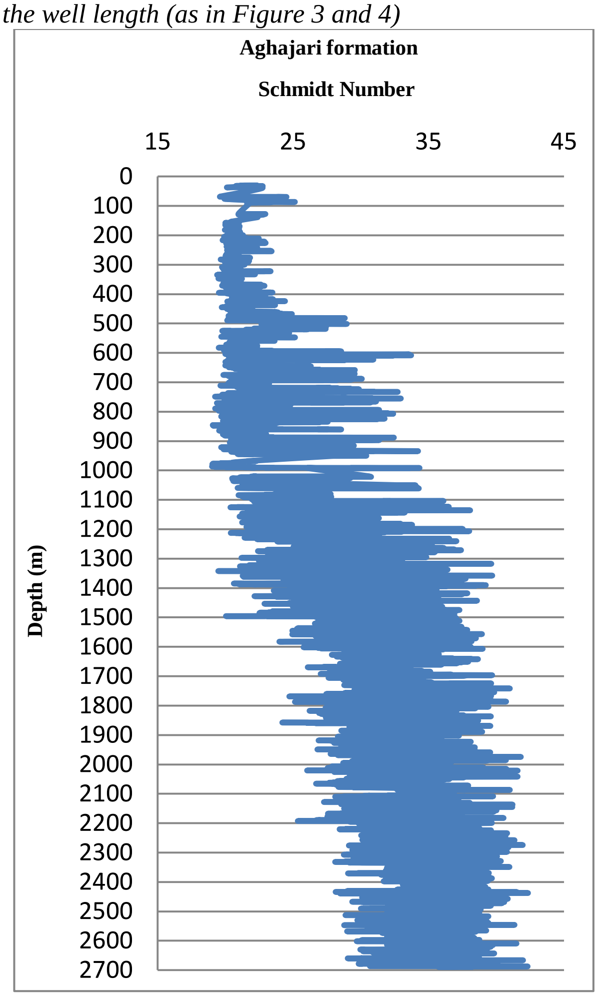

Figure 3. Schmidt rebound number for Aghajari formation

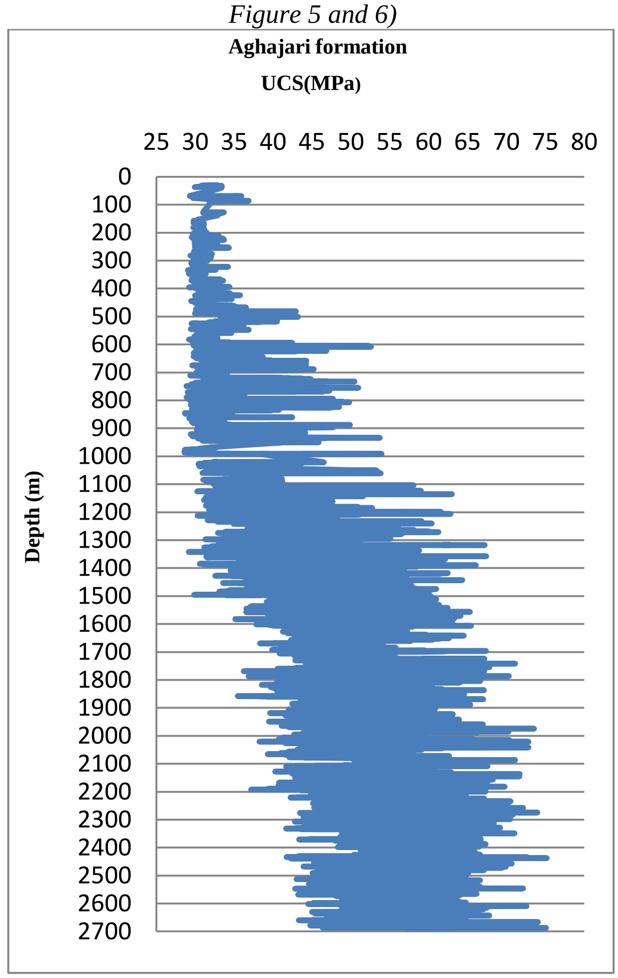

Figure 5. UCS for Aghajari formation

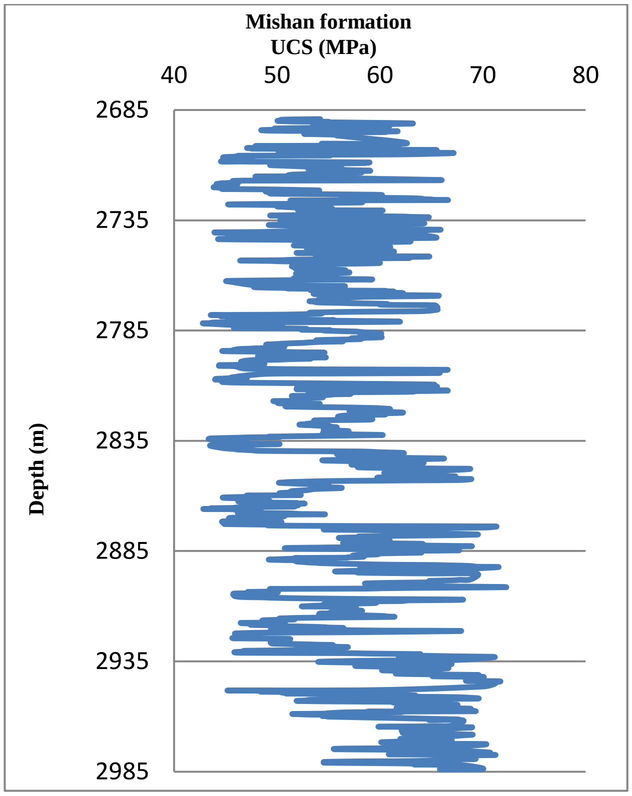

Figure 6. UCS for Mishan formation

7. Roller-cone bit-selection

The following information was obtained to select an appropriate roller cone bit according to the IADC Table:

- Well formation tops from daily drilling reports or sonic logs (Table 3)
- Petrophysical logs including DSI (Dipole shear sonic) and density log
- Continuous estimation of elastic modulus of the well length (Figure 1 and 2)

estimation of elastic modulus of the well length (Figure 1 and 2)

In the next step average value of N and UCS and drillability class for these formations were obtained as in Table 3. Therefore, form IADC table we could identify two-digit number of bit code representing the cutting structure. However, the third digit of the IADC code (the feature code) was left off to allow engineers to determine the type of gauge protection and/or bearing life from offset records. Sometimes the bit records show that the bit suffers from bearing failure and is pulled under gauge, while cutting structure is still acceptable and the log data demonstrates simple (almost unvarying) well lithology profile. In these situations, engineers can decide that a bit with premium bearing or extra gauge protection would supply the needed hours [3]. Finally, we obtained bearing and gauge feature (third-digit IADC code) requirements on the basis of offset well bit records for studied formations plus supplementary information on bearing performance in National Iranian Oil Company in maroon field.

The third number indicates the bearing design and gage protection and consists of the following seven (7) categories [13]:

1. Non-Sealed (Open) Roller Bearing
2. Roller Bearing Air Cooled
3. Non-Sealed (Open) Roller Bearing Gage Protected
4. Sealed Roller Bearing
5. Sealed Roller Bearing Gage Protected
6. Sealed Friction Bearing
7. Sealed Friction Bearing Gage Protected

The appropriate manufacturer's bit name can then be chosen from the IADC bit charts. Finally the mentioned bits in Table 3 are selected for each formation.

8. Bit Selection Program

Using MATLAB codes we developed computer software for bit selection according to the described method. In this software density log and acoustic wave transient time and the type of the bearing is given as input. Then hardness and Young's modulus are calculated, finally the software will recommend appropriate bit based on the IADC code. This program could help drilling engineers to identify geomechanical properties; classify the layers and recommend bit planning. A Graphical User Interface (GUI) built to perform interactive tasks is illustrates in Figure 7.

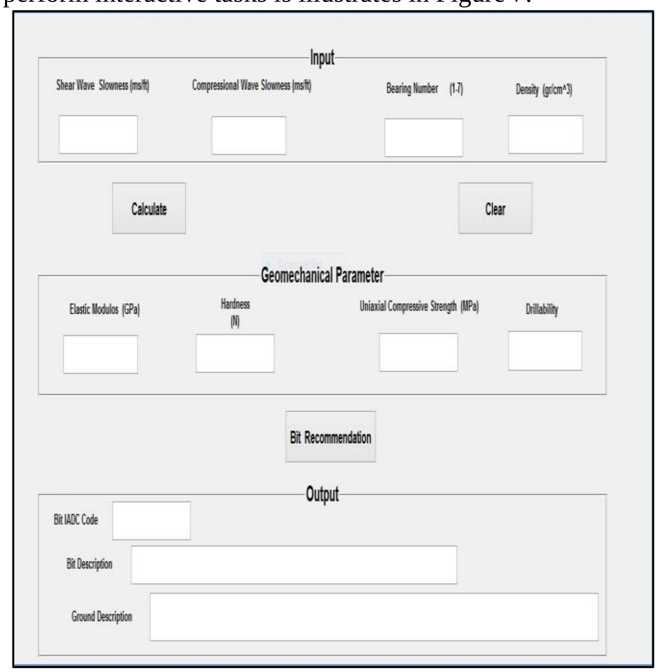

Figure 7. Software Graphical User Interface for interactive bit selection

Table 1. Rock drillability classification based on the Mohs scale [7]

Hardness in Mohs scale	UCS (MPa)	Classification
<7	200<	Very high
6-7	120-200	High
4.5-6	60-120	Moderate
3-4.5	30-60	Tendentious to weak
2-3	10-30	Weak
1-2	10>	Very weak

9. CONCLUSIONS

In this paper we established essential characteristics of formation drillability namely uniaxial compressive strength and hardness based on the petrophysical logs, daily drilling reports and bit records of the offset wells. We demonstrated how exactly bit selection scheme can be established to

Table 2. IADC table for bit selection

IADC Code			BIT Description	Hardness	UCS (MPa)	Ground Description
3	1	1	Steel Tooth Standard Open Bearing Roller Bit	≤ 15	40 - 65	Hard abrasive rocks such as: sandstone with quartz binder, Hard sandstones, hard quartz shales, magma and metamorphic rocks
3	1	2	Steel Tooth Standard Open Air Cooled Bearing Roller Bit			
3	1	3	Steel Tooth Standard Open Bearing Roller Bit with Gauge Protection			
3	1	4	Steel Tooth Sealed Roller Bearing Bit			
3	1	5	Steel Tooth Sealed Roller Bearing Bit with Gauge Protection			
3	1	6	Steel Tooth Journal Sealed Bearing Bit			
3	1	7	Steel Tooth Journal Sealed Bearing Bit with Gauge Protection			
3	2	1	Steel Tooth Standard Open Bearing Roller Bit	15 - 30		
3	2	2	Steel Tooth Standard Open Air Cooled Bearing Roller Bit			
3	2	3	Steel Tooth Standard Open Bearing Roller Bit with Gauge Protection			
3	2	4	Steel Tooth Sealed Roller Bearing Bit			
3	2	5	Steel Tooth Sealed Roller Bearing Bit with Gauge Protection			
3	2	6	Steel Tooth Journal Sealed Bearing Bit			
3	2	7	Steel Tooth Journal Sealed Bearing Bit with Gauge Protection			
3	3	1	Steel Tooth Standard Open Bearing Roller Bit	30 - 45		
3	3	2	Steel Tooth Standard Open Air Cooled Bearing Roller Bit			
3	3	3	Steel Tooth Standard Open Bearing Roller Bit with Gauge Protection			
3	3	4	Steel Tooth Sealed Roller Bearing Bit			
3	3	5	Steel Tooth Sealed Roller Bearing Bit with Gauge Protection			
3	3	6	Steel Tooth Journal Sealed Bearing Bit			
3	3	7	Steel Tooth Journal Sealed Bearing Bit with Gauge Protection			
3	4	1	Steel Tooth Standard Open Bearing Roller Bit	45 ≤		
3	4	2	Steel Tooth Standard Open Air Cooled Bearing Roller Bit			
3	4	3	Steel Tooth Standard Open Bearing Roller Bit with Gauge Protection			
3	4	4	Steel Tooth Sealed Roller Bearing Bit			
3	4	5	Steel Tooth Sealed Roller Bearing Bit with Gauge Protection			
3	4	6	Steel Tooth Journal Sealed Bearing Bit			
3	4	7	Steel Tooth Journal Sealed Bearing Bit with Gauge Protection			

Table 3. Formation characteristics

Formation	Depth (m)	Drillability class	Average Schmidt rebound number (N)	Average UCS (MPa)	Selected bit code
Aghajari	0-2689	Tendentious to weak	28.08	42.95	327
Mishan	2689-2984	Tendentious to weak	34.86	55.51	337

optimize penetration rate and improve bit run length and the number of tripping operations. This could result in reduced overall drilling time, and operation cost because of good compatibility of new bits with the formations. With the procedures described, a much-improved bit program could be achieved in the field. This would help reduce the cost associated with the current trial-and-error procedure and help manage an optimum bit program earlier in the development of the field.

The cost of suggested approach is low, because we could replace the expensive and time consuming coring and the laboratory test with alternative options, as we used compressional and shear sonic velocities for determining the rock mechanic parameters instead of the destructive core test.

10. ACKNOWLEDGEMENT

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11. Nomenclature

IADC: International Association of Drilling Contractors
UCS: Uniaxial Compressive Strength
N: Schmidt Hammer Rebound Number
V_{s}: Shear Wave Velocity
V_{p}: Compressional Wave Velocity
E: Young Modulus
c: Cohesion
φ: Angle of Internal Friction
υ: Poisson’s Ration
ρ: Density
GUI: Graphical User Interface
NIOC: National Iranian Oil Company

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