Assessing Rock Compressive Strength and Predicting Formation Drillability using Sonic, Gamma & Density Logs

Sanjay K. Shrivastava*, Ahmad Javed, K.Krishna Pratap

Summary

Formation Drillability is one of the most important aspects for planning and designing a new oil/gas well since the factors affecting the drilling performance have complex relationships between Formation Properties, Drilling Bit Design and Operational parameters.

In this study, Sonic, Gamma and Density digitized logs have been extensively used as Logs are the real indicator of formation drillability and also represent one or the other physical properties of formation. Rock Compressive Strength has been calculated based on Compressional / Shear travel time (Sonic log), Bulk density (Density log), Shale content (Gamma log) and detailed depth wise Lithology of offset wells.

Globally Rock Compressive Strength is calculated using proprietary softwares by Bit manufacturers to decide on formation drillability aspects but in the absence of any such software with ONGC, an effort has been made to evaluate formation drillability using standard tables, charts, formulae based on the best Industry experience and practices. Considering this as inputs a Computer-Spread-sheet Programme has been developed in-house at Institute of Drilling Technology which computes Rock Compressive Strength.

In view of high operating cost of Drilling Rigs, if Rate of Penetration can be enhanced by any means, it will reduce open-hole formation exposure time & any complications associated with it and eventually significant savings in Drilling Time & Drilling Cost can be realized. Keeping this motto in mind, Compressive Strength studies for 25 major ONGC’s Onshore development fields have been worked out.

Based on Rock Compressive Strength, recommended Bit Selection in different fields has been implemented. Very encouraging results are being acknowledged from fields and on an average there is an increase of 150% to 300% in ‘Formation-Drillability’ has been reported from different ONGC fields.

Introduction

Drilling bit is the most important and crucial tool for smooth and economic drilling of an oil well. Around 120 rig-days per year have been lost in ONGC due to Bit Failures based on last three years complications data. Technological advances in bit design and cutter technology are greatly assisting drilling engineers in bit selection for any given application. Now-a-days great emphasis is given to petro-physical properties of formations for selection of appropriate bit, since these properties have direct bearing on bit life. Compressive Strength analysis has been widely accepted as a key formation property for determining the drillability of formations.

Leading Bit manufacturers like Hughes, Smith, and Halliburton recommend, manufacture & supply bits based on formation characteristics (Compressive Strength) which is calculated by using propriety softwares. They use formation logs primarily Sonic, Gamma & Density logs in digitized form as inputs which they feed in their softwares & offer a particular bit suitable for a particular formation.

In the present paper wells drilled in Assam, Tripura, Kolkata, Krishna Godavari Project (Rajahmundry),
Karaikal (Cauvery), Ahmedabad Ankleshwar, Mehsana and Frontier Basin have been analyzed. Accordingly Milled Steel-Tooth, Tungsten-Carbide Insert, PDC and Impregnated Bits have been recommended to different ONGC onshore fields based on the study which are being trial tested. The results realized so far have been encouraging from ROP/drillability point of view. This paper will help field engineers in improved and cost efficient ‘Bit Selection’ predominantly for 17½”, 12¼” & 8½” phases.

Bit selection by IADC code is prevalent everywhere, considerations for assigning IADC code to a bit by manufacturer are not broad based. Though, IADC code gives a picture of intended formation application, still two different bits of same IADC code may differ in design details, quality and performance. With advancements in metallurgy, cutting structure, bearing, gauge protection, fluid course, nozzle orientation, a number of bits are available with same IADC code but with different special features and hence a drilling engineer has to be very specific about bit selection. Now it has been established that attributes/features of TCR bits play an important role, so an effort has been made in this paper to evaluate the compressive strength and correlate drillability aspect of the formation.

The method followed for evaluating compressive strength is based on Compressive Strength using Sonic, Gamma & Density logs. Digitized value of compressional travel time, gamma ray log and bulk density are put in formulae to find the compressive strength of these formations (Fig. 3) and plotted against depth as shown in Fig. 4 & 5. This plot is then used to select a suitable bit for any desired interval.

Conventional Bit Selection Methods

There are several methods prevalent for bit selection, such as Cost per Meter method, Dull Bit Grading method, Offset Bit Record method, Specific Energy methods etc.

The commonly used criteria for selecting the bit for the next interval is the bit type with the highest ROP or the bit with minimum Cost per Meter. In addition, factors such as hydraulics, formation hardness, bit design, and operational parameters are considered in the selection process. Due to the number of variables considered, the selection process is a trial and error procedure. In many cases, this approach can ignore some of the important parameters affecting the bit performance and cannot guarantee selection of the optimum bit type.

The problem with using Offset Bit Record method is that they contain no lithology or strength information. Bit records indicate only how the bits performed over the intervals drilled and under what conditions they were operated. All these methods, in-fact reflect the bit capability i.e. individual bit’s efficiency to drill a formation and not the formation drillability. Thus a bit selected on the basis of above methods will only give an idea about the performance of selected bit with respect to previously used bits.

The log values assist the Drilling Engineer in making economical bit selections. In case of present study, different types of logs have been extensively used which represent one or the other physical properties of the formation. Thus the selected bit has direct bearing on formation properties. Once the field is mapped in respect of compressive strength, the formation can be categorized as soft, medium, hard etc. Such grouping of formation will help in selecting a suitable bit for a particular formation.

Various indirect measuring techniques are presently employed for estimating formation strength, which in turn, is correlated with drillability and bit selection. Formation drillability is best determined from Unconfined Compressive Strength (UCS). It is one of the most basic parameters of rock strength, and most common determination performed for boreability predictions. The unconfined (or uniaxial) compressive strength (UCS) of a rock is a common measure of the strength of intact rock. It is normally measured on cylinders of rock core by compressing the core between two platens and measuring the maximum load at which failure occurs.

Log Based Bit Selection Method

Identified 5 to 6 drilled wells in identified fields.

Recorded broad lithology, well configuration and casing policy followed in each field.

Collected Sonic, Gamma and Bulk Density logs for 17 ½”, 12 ¼” & 8 ½” phases in digitized form.

Developed a computer spreadsheet programme with the help of standard empirical formulae / tables (Fig. 4) and entered the digitized log data in respect of selected wells.
Calculated the UCS for each 15 centimeters. Took moving average of 3 meters to avoid sharp ups and down and plotted the same against the depth. (Fig. 5)

Drew charts between Compressive Strength and Depth for 17½”, 12¼” & 8½” Phases for concerned fields (Fig. 4 & 5).

With the help of IADC, TCR & PDC Bits classification charts and Bit Selection Guide for most economic Bits Selection (Fig. 1), made the criteria and classified the intervals as (Very soft, Soft & Sticky, Soft, Soft Medium, Medium, Medium Hard, Hard and Extremely Hard) for selection of TCR and PDC bits (Fig.6).

Studied the performance of previously used bits in these fields. Noticed the attributes of such bits, their wear pattern, bit life and reasons for poor performance.

Recommended suitable bits for different fields based on inputs/analysis and observations (Fig.11).

**Techno-Economics : Results based on Log Based Bit Selection**

Performance comparison has been analysed with Log based Bit Selection and conventional Bit Selection and shown in Fig. 9, 10, 11 & 12.

**Geleki Field (Assam):**

Two recently drilled wells G-191-A & GCG (with Log based Bit Selection) have been compared with their offset wells GKED & GKBF respectively (Fig. 7 & 8):

- 12 Days each could be saved on each well.
- Approx. 70 $/M could be saved on GCG well of 4200 TD.
- 150 % increase in ROP on both the wells.
- Well G-191-A could be completed with only 7 bits as against 20 on offset well. So saving of 13 bits cost & saving of 13 trips.

**Lakwa Field (Assam):**

Performance comparison has been made for 12¼” phase of 1600m section of well LKAU (offset LMAA), where Log-based Bit Selection could attain ROP 14 M/Hr against 9 M/Hr. & section was completed in just 5 days (Fig.11). So, LKAU Cost/Meter also came down to just 66 % as compared to its offset well as shown in Fig.9.

**Jabera Field (Frontier Basin):**

Performance comparison has been made for 17½” phase of 1500m section of very hard formation (Fig.10), where conventional bit-selection could attain hardly 16m/bit as against 119m/bit with Log based Bit Selection. ROP achieved was more than 150 %, thus Cost/Meter came down to almost half.

**Conclusion and Recommendations**

Prevailing methods of bit selection like Cost per Meter, Dull Bit Grading, Offset Bit Record and Specific Energy methods in-fact reflect the bit capability i.e. individual bit’s efficiency to drill a formation and not the formation drillability. Logs, not bit records are an indicator of what a bit penetrated. Therefore, the log values support in making economical bit selections.

Suitable Bit Selection have been recommended to all concerned fields for 17 ½”, 12¼” & 8½” phases. Very encouraging and positive outcomes are being received from different work centers where the recommended bits are being trial tested. In general, following are the recommendations based on the compressive strength study:

- Special featured, high performance TCR bits or suitable PDC bits may be preferred (Fig. 2) for long sections having comparable Compressive Strengths in 17 ½”, 12¼” & 8½” sections for improved ROP and cost benefits due to reduced numbers of trips resulting in fewer complications.
- The Matrix body for PDC bit is suggested to avoid erosion due to sand/sand stone if encountered during drilling. Also Matrix body PDC bit is suggested for long sections to cover entire section to avoid intermediate bit change instead of lowering Steel bodied PDC bit of same IADC code first and then switching over to Matrix bodied PDC bit.
- Hydraulics is vital as it improves bottom hole cleaning and ROP. So, maximum possible Discharge should be maintained while using PDC Bits.
Nomenclature

PDC : Polycrystalline Diamond Compact
TCR : Tri Cone Roller
ROP : Rate of Penetration [Meter/Hour]
TD : Target Depth [Meter]
UCS : Unconfined Compressive Strength [PSI]
IADC : International Association of Drilling Contractors
GPM : Gallons Per Minute
C/M : Cost Per Meter
DBG : Dull Bit Grading
OBR : Offset Bit Record
SE : Specific Energy

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- 37582 “Improved Roller Cone Bit Selection through the use of an attribute based Bit Classification System”.
- 13256 “Three Cone Bit Selection with Sonic Logs”.
- 18166 “Relationships between Formation Strength, Drilling Strength and Electric Log Properties”.
- 11032 “Shear Wave Travel Time Determination Using an unconventional approach”.
- 77217 “Cumulative Rock Strength as a quantitative means of Bit Selection & Emerging PCD Cutter Technology”
Fig. 3: Glimpse of Computer Spread Sheet Programme to evaluate Compressive Strength of formations using Sonic, Gamma & Bulk Density Logs.

Fig. 4: Compressive Strength vs Depth Charts for 12¼” & 8½” Phase in Periyapatnam (Cauvery Field).

Fig. 5: Compressive Strength vs Depth Charts for Assam (Laipling Gaon) & KG (Pasarlapudi) Fields.
**Fig. 6**: Bit Selection Guides for Roller Cone & PDC (Polycrystalline Diamond Compact) Bits

**Fig. 7**: No. of Drilling Days and Drilling Cost comparison in Geleki, Assam Wells (Comparison between G-191-A & GCG with their offset wells GKED & GKB)

**Fig. 8**: Average ROP and No. of Bits Consumption comparison in Geleki, Assam Wells (Comparison between G-191-A & GCG with their offset wells GKED & GKB)
Fig. 9: No. of Drilling Days in 12¼” Phase and Drilling Cost comparison in Lakwa, Assam Well (Comparison between LKAU & its offset well LMAA)

Fig. 10: Meterage per Bit and Drilling Cost comparison in Frontier Basin Well (Comparison between Jabera #2 & its offset well Jabera #1)

Fig. 11: “Bit Selection” accomplished for major fields in above area