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Remodelling Bit Selection Models

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Abstract: **Hitherto our drilling industry is disturbed with challenges of optimal bit selection due to the fact that current bit models in market are bias to very hard Formation like Hard Streak. At Soku Oil field of Niger Delta, Nigeria, West Coast of Africa, there exits challenges in the proper bit to drill the section of the hard Formation, which is associated with siliceous-ferrogenous sandstone with traces of siltstone rapped in augen of shale. This segment of formation affects every inch of drilling – from the bit in the drilling string to drilling tools, mud, hole diameter and general rig operation. Engineers that specialize in bit optimization, including Directional Drillers, possess the analytical skill to evaluate drilling problems in a methodical fashion, carefully considering the larger context of the drilling process. Therefore, to tackle the menace of the hard streak, great experience, regrouping and remodelling of the existing models were done. Data for this study were gathered through personal observation as a Directional Driller at Soku field. Others were from Shell, Nigerian National Petroleum Corporation (NNPC), Directorate of Petroleum Resources (DPR) and further research from internet. The data were subjected to analytical methods, presented in tables, figures and charts. Based on the data analysis, the findings of the study are that:**

- **Insert bits are perfectly good to drill all sections of hard streak provided rotation at bottom is not more than 36 hours, less cones are lost.**
- **The use of PDC bits to drill or ream through the hard streak is an aberration while insert bit (447) is the best for drilling hard streak.**
- **Regrouping of International Association of Drilling Companies (IADC) Code and remodelling of current models in the market were inevitable to accommodate selection of bits for the hard streak.**
- **The use of steerable motor all through a hard streak to reduce axial lateral vibration on Drilling String is recommended.**

Keywords: **Hitherto our drilling industry, PDC bits, Directorate of Petroleum Resources (DPR).**

1. INTRODUCTION

The objectives of this study are to:

- Examine the drilability issues in hard streak Formation, limitations of former workers' models in tackling it and develop an improved models to handle the drilability issues through proper bit selection.
- Develop models that will take care of soft, hard and very hard Formation.
- Enable drillers select bits before and during drilling operations

2. THEORETICAL BACKGROUND

As part of drive to tackle problems in Soku Field as a result of hard streak phenomenon, efforts are made to study the nature of the hard streak and how to drill holes through it without losing the holes or the drill strings. The hard streak, which starts from about 6113 till 6390 ft or 6280 to 7160ft in previous wells, are siliceous-ferrogenous sandstone, with traces of siltstone rapped in augen of shale. They have filling ability on the PDC because they are highly consolidated and cemented with haematite. Drilling through the tight streaks constitutes a high risk to the drilling assembly with high axial vibrations (bit bounce), hence it is the responsibility of the Directional Driller to optimize drilling parameters to minimize the overall impact.

From this research, the only good bit for this section is Tricone insert (447) bit because of its fracturing ability on the hard streak. Therefore, great experience and knowledge of geology of the area is very important for any successful hole drill.

Soku field is an offshore oil and gas field, concession of Shell Petroleum Development Company (SPDC) located in Swampy Area of Niger Delta.

Fast and economical penetration depends on the mineralogical structure of the rock, drilling machine, geomechanic characteristics, the driller used and the choice of drilling tools appropriate to the rock (Onan and Müftüo_lu, 1993)

According to Chevron's rock mechanics, efforts and proven strength in formation characterization have driven the development of the SeROP Predictor Tool to quantify and reduce the invisible lost-time component of drilling and tripping costs. This is accomplished by:

- Characterizing the formation to be drilled (unconfined strength, confined strength, abrasiveness, lithology, etc.)
- Selecting the right bit based on formation characterization
- Projecting the maximum target ROP in each formation
- Increasing the ROP performance of the bit on the theoretical maximum
- Maintaining optimal drilling parameters for the life of the bit.
- Knowing when to replace the bit when performance is sub-optimal.

The most important component of the SeROP Predictor Tool is the incorporation of CCS, which differs from existing ROP analysis and prediction methods that are based solely on unconfined compressive strength (UCS). UCS predictions are problematic and erroneous because UCS does not represent the "apparent' strength as the rock-bit interface. CCS is defined as the increased compressive strength of a rock from the pressure differential between the borehole pressure and the formation fluid pressure. CCS better represents the "apparent' rock strength in overbalanced drilling environments.

All things been equal, factors that drive or limit the drilling rate of penetration can be placed into two distinct categories; that is, energy input and efficiency factors that determine energy input are shown in the following ROP calculation:

$$ROP = \frac{13.33 * \mu * \mathrm{N}}{D_{\mathrm{B}}\left(\frac{CCS}{Eff_{\mathrm{M}} * WOB} - \frac{1}{Aa}\right)}$$

Where: μ = Bit-Specific coefficient of sliding Friction (unitless)

N = RPM

D_a = Bit size (inches)

CCS = Confined compressive strength of the rock (psi)

Eff_M = mechanical Efficiency of the bit

WOB = Weight On Bit (pounds)

A_B = Borechole area (square-inch)

As expressed above, the bit-specific coefficient of sliding friction (μ) expresses torque as a function of WOB and an integral function of the SeROP predictor tool is the calculation of μ and Eff_M derived from full-scale simulator tests using several different rock samples and bit types.

Bit selection remains primarily performance driven. However, using the rock mechanics approach to couple bit selection with formation characterization allows the user to quantitatively asses drilling efficiency and identify areas of ROP improvement.

Hector U et al discussed the Unique ROP Predictor using Bit-Specific Coefficient of Sliding Friction and Mechanical Efficiency as a function of Confined Compressive Strength Impact Drilling Performance. Chevron Exploration and Production Technology Company (EPTC) initiated work on a project to improve drilling performance and pre-drill performance prediction based on a Mechanical Earth Model (MEM). Required components of this project were pre-drill bit selection, rate of penetration (ROP) prediction, and bit life predication.

3. FIELD APPLICATIONS

This thesis outlines the various analytical results obtained from applied method. **REGROUPING** of the International Association of Drilling Companies (IADC) and **REMODELLING** of Teales equation, removing the bearier tagged by 5%-20% Effective Porosity of Skemptons window is the key to new bit selection models.

From the analogue core data and the gamma ray logs of the correlating wells of Soku Oil Field, the F1000 shows a coarsening upwards sequence, consistent with mouthbar deposit at the base. This basal sand is overlain by blocky – fining upwards sand at the top. The interval is interpreted to be channel sand deposits cutting into proximal and distal mouthbar facies. The sand is some 110ft thick, with good reservoir qualities. Average porosity is about 0.25 p.u, while permeability is in the Darcy range. The Net/Gross of the interval is estimated to be 0.79. Before this sand is the hard streak.

Hard Streaks is very hard, cemented sands in overburden (ca. 6000-7000 ftss) have caused drilling problems in all Soku wells. But this challenge motivated the research for optimal bit selection that will take care of soft, hard and very hard Formation as we perfected models on it's bit selection. This involved re-grouping of International Association of Drilling Companies (IADC) code and remodelling of Teales and Skeptom's equations.

Having considered Skempton's model which only considered formation with effective porosity between 5-20%, leaving behind formation below 5%, in which the hard streak falls within, we were obviously left to seeking solution that would handle the inadequacies of his model, hence petrology of the streak, bit grouping in IADC and remodelling of Teales equation to make credence to division of formational rock into soft (loose sand), hard (shale) and very hard (hard streak).were key and researched upon as expatiated below.

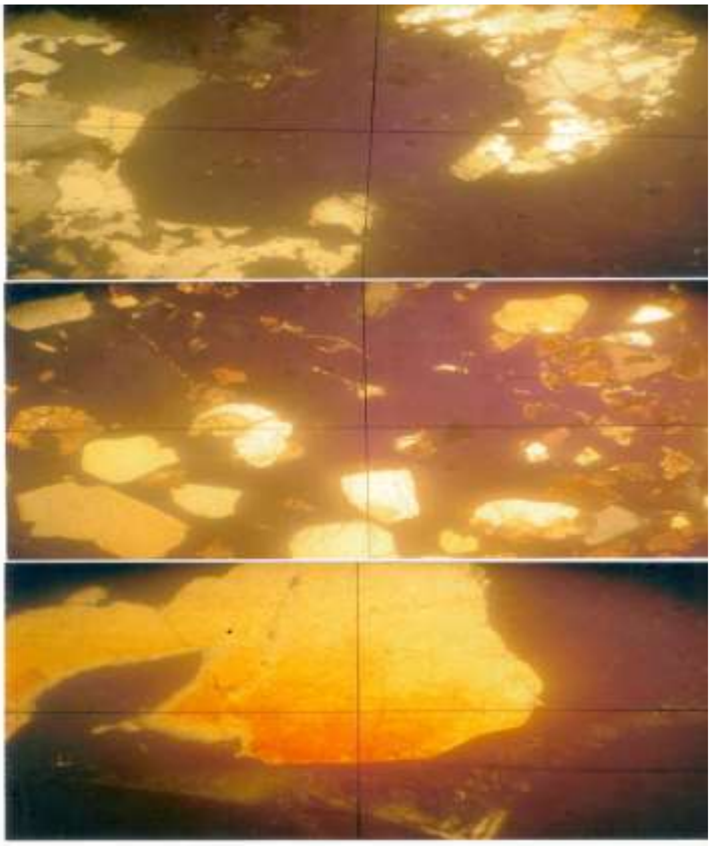

Fig 1: Cross-Section Of Rock Sample In Slides

Above is a cross-section of slides exhibit - Quartz (monocrystalline 95%, polycrystalline 5%), stained 9% by haematite, cementation – Haematite (brown/red – oxidized and medium energy environment), traces of muscovite flake. Sediment type – quartz arenite, Rock Type – Quartzite, a constituent of a bed, immature (not far from the source).

The next research was on the type of bit that has capacity and capability to drill through the hard streak. Results of previous Rate of Penetration (ROP) as explained below enabled us to regroup bits in accordance to IADC CODE as shown in the table below.

Table 1: Iadc Code Grouping By Author

IADC CODE				
EXAMPLE OF IADC CODE e.g 515	5	1	5	0
	TOOTH SERIES	**FORMATION TYPE**	**STANDARD FEATURES**	**SPECIAL FEATURES**
TOOTH SERIES (Numbers 1-8): Numbers 1-3 indicate the bit has milled steel. Number 4-8 indicate the bit has tungsten carbide insert teeth. Smaller numbers indicate fewer & longer teeth for soft formation while higher numbers indication of more but shorter teeth for hard and abrasive formation. **FORMATION TYPE** (Numbers 1-4): Within each series the formation relative to the tooth series while higher numbers indicate hard formation relative to the tooth series. **STANDARD FEATURES** (Numbers 1-7): These numbers indicate the type of bit bearing ring and the presence of Gauge protection. **Below shows the grouping of the IADC CODE that enabled the formulation of my models**				
1-3	**CUTTER TYPE LOW STRENGHT i.e LOW UNIAXIAL COMPRESSIVE STRENGHT (UCS)**			**GP 1**
4-5	**MEDIUM TO HARD STRENGTH CUTTER i.e MEDIUM (UCS)**			**GP 2**
6-8	**HARD i.e HIGH (UCS)**			**GP 3**
For example, a bit of 447 means UCS is 4 i,e medium to hard. Bit has tungsten carbide insert teeth				
Though smaller numbers indicative of fewer but longer teeth for soft formation (Sandstone)				
The next numerals 4 means formation is hard and 7 indicatives bit has seal friction bearing with gauge protection. This is an indicative of hard streak by this research.				

Engineers that specialize in Drill Bit Optimization, including Directional Drillers, possess the analytical skill to evaluate drilling problems in a methodical fashion, carefully considering the larger context of the drilling process. Engineers examine the drilling operation from every angle to identify factors that might influence bit performance. Hence, understanding the symptoms and accurately diagnosing the root causes, drilling problems are corrected at the source. Armed with a complete picture of the drilling environment, the drill bit optimization engineer can match ideal drilling and bit technologies to customer specific applications and objectives

4. WHAT WE DID DIFFERENTLY: MODEL RESULTS

With reference to:

$$ROP = \frac{13.33 * \mu * N}{D_B\left(\frac{CCS}{Eff_M * WOB} - \frac{1}{Aa}\right)} \quad ....1$$

Where: μ = Bit-Specific coefficient of sliding Friction (unitless)

N = RPM

D_a = Bit size (inches)

CCS = Confined compressive strength of the rock (psi)

Eff_M = mechanical Efficiency of the bit

WOB = Weight On Bit (pounds)

A_B = Borechole area (square-inch).

Also combining above with Pessier validated equation for drilling under hydrostatic pressure.

$$Es = \frac{WOB}{Aa} + \frac{120 * \Pi * N * T}{Aa * ROP} \quad ....2$$

Where: Es = specific energy (psi)

WOB = weight on bit (pounds)

As = Borehole area (sq-m)

N = rpm

T = torque (ft -Ibf)

ROP = Rate of penetration (ft/hr)

Research on accurate confined compressive strength (CCS) to the bit failed because performance (ROP) and bit life is improved with the proper application of Specific Energy (Es) methods coupled with (CCS) calculations and Formation characterization capability. Noticed that Mineralogical Structure of the rock & drilling parameters guided us to the bits that have cutting action by compression fracturing – a practical field experience.

Rock Origin, characterization, matrix (Haematite) & cementation (Haematite) enabled models on soft, hard & very hard formation. To account for the very hard formation (hard streak) which my project is trying to solve, we then refer back to Skempton and Teale's equations respectively:

CCS_MIX = CCS_DP if phie>.20 = CCS_SK if phie<.05...3

= CCS_DP(Phie-0.5)/.15+CS_SK(.20-Phie)/.15 , If.05<Phie<.20 4

Where: Phie = effective porosity

Knowing that T= {(CCS/ Eff_M)-(4*WOB)/(ii* Db^2) *(Db^2 *ROP)/(480*N)}.

ROP=13.33* µ *N/{Db(CCS/ ($Eff_{M\ *\ WOB)}$ - (1/Ab)}.

CCS = UCS+DP+2DP*sinFA/(1-sinFA).

CCS_DP = UCS+DP+2DP*sinFA/(1-sinFA).

Teale's equation, Eff_M = (Esmin/Es)*100 or Eff_M α 100(ZUCS/Es) when specific energy, Es approaches or ≈ the compressive strength of the bit type and where: Minimum Specific Energy is Esmin & Rock bit Strength or Maximum Mechanical Efficiency is Effm.

The Esmin that was able to break the hard streak from our field parameters can be expressed as ZUCS, where UCS is uniaxial compressive strength. Therefore Teale's equation can be re-written as shown below:

MODIFICATION OF TEALE'S EQUATION

From: $$ROP = \frac{13.33\mu N}{D_b\left(\frac{CCS}{Eff_m \times WOB - 1/A_b}\right)} \quad 1$$

$$\mu = 36\frac{T}{D_b \times WOB} \quad 2$$

$$CCS = UCS + DP + 2DP\frac{\sin FA}{1-\sin FA} \quad 3$$

TEALE'S EQN: $$Eff_m \alpha 100(Es\min / E_s) \quad 4$$

MODIFICATION OF TEALE'S EQN: $$Eff_m = 100k(Z \times UCS / E_s) \quad 5$$

$$E_s = \frac{20 \times WOB \times N \times t_r}{D_b \times F} \quad 6$$

$$Z = \begin{cases} 1, \text{ soft formation} \\ 2, \text{ hard (shale) formation} \\ 3, \text{ very hard fm (hard streak)} \end{cases} \quad 7$$

IADC CODE

Numbers 1-8	Numbers 1-4	Numbers 1-7	C
TOOTH SERIES	FORMATION TYPE	STANDARD FEATURES	SPECIAL FEATURES

Z is the re-grouped bit Standard Tooth Series from IADC where:

Tooth Series numbers 1-3 is GROUP 1 = Z_1 = 1, for soft fm

Tooth Series Number 4-5 is GROUP 2 = Z_2 = 2, for hard (shale fm)

Tooth Series Number 6-8 is GROUP 3 = Z_3 = 3, for very hard fm (hard streak

Min. Specific Energy = Es min = ZxUCS

ROP = Rate of penetration, ft/hr

WOB = weight on bit

N = frequency, rpm

D_b = borehole diameter, in

A_b = borehole area, in^2

μ = Bit specific coefficient of sliding friction, dimensionless

T = Bit torque, ft-lbf

CCS = confined rock compressive strength

UCS = uniniaxal compressive strength of bite

DP = differential pressure

FA = rock internal angle of friction

Assumptions:

Z = Re-grouped bit standard tooth series, assumed to be 3 for hard streak.

When Z = 3, Es ~ compressive strength of bit type

k = constant that must be chosen based on when Effective Porosity<5%, k=1

tr = Rotation time (mns) ……….. obtainable while drilling

F = Footage drilled (ft) ………… obtainable while drilling

Therefore, Eff_M α 100(ZUCS/Es), where Z is bit Standard Tooth Series group, assumed to be 3 for hard streak. (see table 1 above).

$Eff_{M =}$ k100(3UCS/Es) = Maximum Mechanical Efficiency when specific energy, Es approaches or ≈ the compressive strength of the bit type.

K is a constant which is assumed to be one when effective porosity is <5% for highly cement (haematitic) sandstone.

The problem is solved from proper selection of bit standard group in the IADC – as shown above.

Basically Teale and Skempton's models, (which was the bases for many International Oil Companies - IOCs models) were related to mine until only 5%<20% effective porosity Formation were considered.

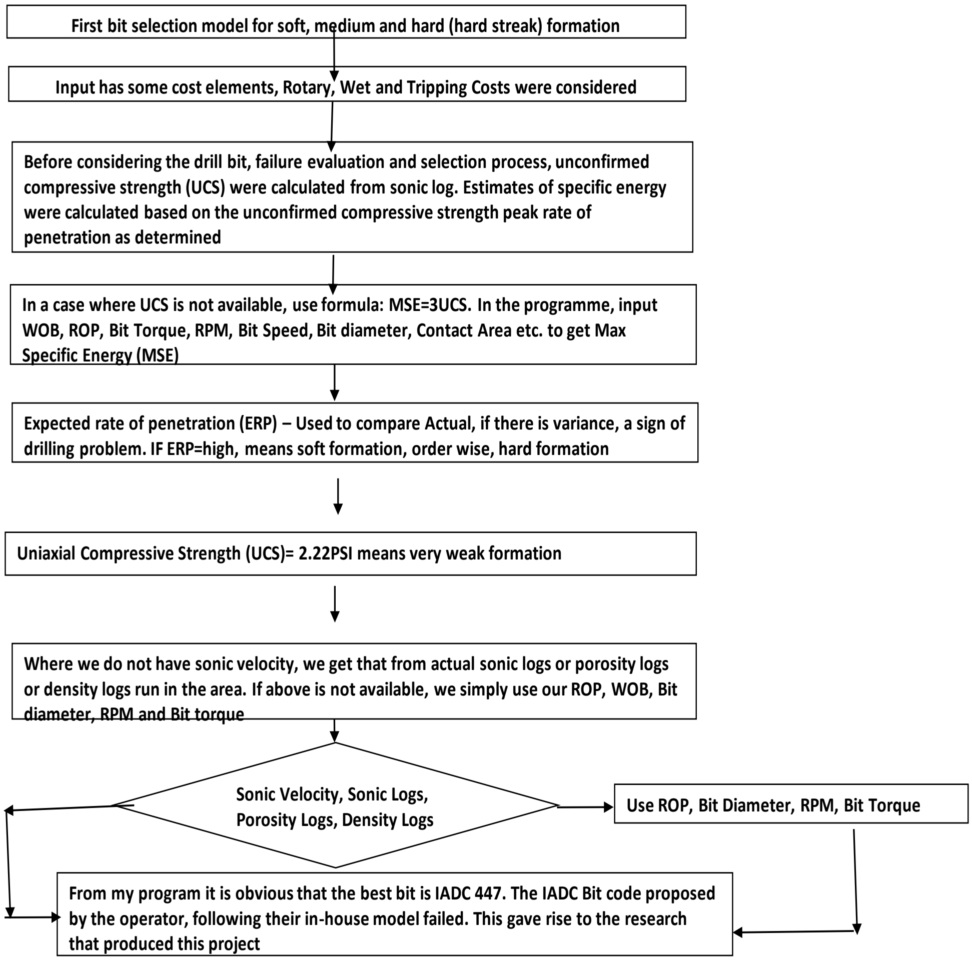

Fig.2: Flow Chart Of My Models

Table 1:First Bit Selection Model For Soft, Medium And Very Hard (Hard Streak):

USE WHILE ALREADY IN THE DRILLING CAMPAIGN.

PARAMETER	
YOUR QUERY	SHALE OR HARD FORMATION
APPROPRIATE DRILLING BIT	PDC, 9 BLADES 13MM (NOTE: DON'T USE TO REAM)
WEIGTH ON BIT IN TONS (WOB)	15
FLOW RATE (FR)	750-950 GALLONS PER MINUTE
ROTATIONS PER MINUTE (RPM)	40
MAX HOURS DOWN HOLE	CAN BE MUCH MORE THAN 36 HOURS
RATE OF PENETRATION IN FEET PER MINUTE (ROP)	30

Above programme helps one select bit while already drilling. In the first programme of the first model, three Formation were involved – sand (soft formation), shale (hard formation) and hard streak or very hard formation. To run the programme see the instructions below:

Select any of the Formation; the appropriate drilling bit in tons appears, with an initial WOB, FR, RPM, ROP etc. Each of these parameters can be changed, with a resultant change in other parameters. It is important to note the different types of bits that are suitable for different Formation. Soft (sand Formation) is suitably drilled with milled tooth, shale (hard Formation) by PDC and Very hard Formation(hard streak) by insert bit (IADC Code: 437-447). You may print out these values by selecting print, very flexible programme, can change paramerters and see the playout..

Table 2: Second Bit Selection Model For Soft, Hard And Very Hard (Hard Streak) Formation

PARAMETER	
YOUR QUERY	SAND OR SOFT FORMATION
APPROPRIATE DRILLING BIT	MILED TOOTH 3000’
WEIGTH ON BIT IN TONS (WOB)	4
FLOW RATE (FR)	750-950 GALLONS PER MINUTE
ROTATIONS PER MINUTE (RPM)	10
MAX HOURS DOWN HOLE	36 HOURS
RATE OF PENETRATION IN FEET PER MINUTE (ROP)	30

PARAMETER	
YOUR QUERY	HARD STREAK OR VERY HARD FORMATION
APPROPRIATE DRILLING BIT	INSERT BIT, IADC CODE: 437-447
WEIGTH ON BIT IN TONS (WOB)	20
FLOW RATE (FR)	750-950 GALLONS PER MINUTE
ROTATIONS PER MINUTE (RPM)	18.0
MAX HOURS DOWN HOLE	36 HOURS
RATE OF PENETRATION IN FEET PER MINUTE (ROP)	7.5

BIT SELECTION DATA INPUT 1	
ENTER TOTAL DEPTH OF INTEREST	5000 FT
ENTER SPEED	170 RPM
ENTER WEIGHT ON BIT	1 T
ENTER BIT DIAMETER	12.25 IN
ENTER VALUE FOR ROP	63
ENTER COMPARATIVE BITS DRILLING COST	#4444
ENTER ROTATING COST	#5555
ENTER TRIP COST	#6666
ENTER NET BIT COST	#7777
RUN	
RESULTS: FORMATION TYPE – SHALE/SAND/SOFT FORMATION ROCK STRENGTH (HARDNESS) – SOFT FORMATION IADC CODE – 313	

Second Bit Selection Model For Soft, Medium And Hard (Hard Streak) Formation – This is use before setting out for drilling campaign. Input has some cost elements: Rotary, wet and tripping costs were considered.

Before considering the drill bit, failure evaluation and selection process, unconfirmed compressive strength were calculated from Sonic Log. Estimates of specific energy were calculated based on the unconfirmed compressive strength peak rate of penetration as determined.

Results from Field:

Uniaxial compressive strength (UCS) = 2.22 psi (mean) very weak formation

Mechanical specific energy (MSE) = 6.817 psi (mean) monitored drilling operations in site.

We need speed limit to avoid vibrationand optimal bit torque to enable rate of penetration, having had good idea of formation strength.

In a case where UCS is not available, we use a formula: MSE=3UCS (resultant substitution using previous equations for proper bit that handled the streak). In the programme, input WOB, ROP, Bit Torque, RPM, Bit Speed, Bit Diameter, Contact Area, etc are to get MSE.

Expected Rate of Penetration (ERP) is used to compare actual rate of penetration. If there is variance, this is a sign of drilling problem. If ERP = High, means soft formation, order wise, hard formation.

Where we do not have sonic velocity, we get that from actual sonic log or porosity log or density log run in the area. If above is not available, we simply use our ROP, WOB, Bit Diameter, RPM, and Bit Torque as actually used here.

Table 3: Second Bit Selection Model For Very Hard (Hard Streak) Formation

BIT SELECTION DATA INPUT 2	
ENTER TOTAL DEPTH OF INTEREST	7000 FT
ENTER SPEED	35 RPM
ENTER WEIGHT ON BIT	12 T
ENTER BIT DIAMETER	12.25
ENTER VALUE FOR ROP	60 FT/H
ENTER COMPARATIVE BITS DRILLING COST	#4444
ENTER ROTATING COST	#5555
ENTER TRIP COST	#6666
ENTER NET BIT COST	#7777
RUN	
RESULTS:FORMATION TYPE –SANDSTONE – VERY HARD/CEMENTEDBY HAEMATITE– HARD STREAK ROCK STRENGTH (HARDNESS) – MEDIUM-HARD FORMATION IADC CODE – 447	

Fig 3: Results Of Second Bit Selection Model

source: Author

The categorization of the IADC code for the bits into groups as stated above is very important key. Notation is that from our programmes, it is obvious that the best bit is IADC 447. The highlighted IADC 415 proposed by operator, following their in-house model, failed us while on the rig, because their models only considered sand and shale Formation. Also Technical Problems with old models are basically on the consideration of only soft (sand) and hard (shale) Formation, on effective porosity between 5<20% as established by Skempton's Equation. Very Hard Formation (Hard Streak) is impermeable (<5% Effective Porosity), therefore Skempton's Equation did not address the problem. This gave rise to the research that developed this project. This is why old models failed and our models solved the problem. Also old workers concentrated on laboratory experiment. For example, power drive mud motor (PDM) at minimum speed and validation of Confined Compressive Strength (CCS) presented from two standpoints lacked practical field imput.

It should be noted that research on accurate Confined Compressive Strength (CCS) to the bit also failed because performance or Rate of Penetration (ROP) and bit life is improved with the proper application of Specific Energy (Es) methods coupled with Confined Compressive Strength (CCS) calculations and Formation characterization capability.

Notice that Mineralogical Structure of the rock and drilling parameters guided us to the bit that has cutting action by compression fracturing – a practical field experience.

In other words, rock origin, characterization, matrix (Haematite) and cementation (Haematite) enabled models on soft, hard and very hard formation.

5. CONCLUSIONS

Arising from the analysis and finding, it is concluded that this project has established the facts that rock mineralogical structure (Petrology) has helped us to understand the matrix/cementation & rock constituents that make up the hard streak. The rock Formation is now grouped into 3 – soft, hard and very hard to accommodate hard streak. The developed models helped us in the proper bit selections.

From comparable economics, the IADC code 447 bit costs only $196 to drill a foot than $120,000 of PDC, thereby saving $1.2M within the hard streaks of 5,000ft.

The by-product of this research is that about 3,000ft to NAG well reservoirs or 7,000ft from surface on land, in GAS PRONE AREAS OF NIGER DELTA (SOKU & UTOROGU), HARD STREAK is eminent.

Therefore, the benefits of this study to drilling industry can be enumerated as follows:

1. Understanding of the nature of hard streak.

2. Good guide to bit selection – PDCs not good in drilling hard streak but insert bits IADC 447 Code is, provided it does not stay more than 36 hours drilling on bottom,

3. Formation is divided into 3 to enable bit selection in soft (unconsolidated sand), shale and hard streak.

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Nomenclature:

Bbl	A standard measure of crude oil
ECD	Equivalent circulating density
MD	Measured Depth
TVD	True Vertical Depth
API	American Petroleum Institute
ROP	Rate of Penetration
RPM	Rotation Per Minute
BHA	Bottom Hole Assembly
DPR	Directorate of Petroleum Resources
NNPC	Nigerian National Petroleum Corporation
3D	Three Dimensions
4D	Four Dimensional (4^{th} dimension being time lapse)
PSC	Production Sharing Contract
STOOIP	Stock Tank Oil in Place

μ = Bit-Specific coefficient of sliding Friction (unitless)
N = RPM
D_a = Bit size (inches)
CCS = Confined compressive strength of the rock (psi)
Eff_M = mechanical efficiency of the bit
WOB = weight on bit (pounds)
A_B = Borechole area (square-inch)
ΔP = pressure drop, psi
P_D = dimensionless pressure drop
P_i = initial reservoir pressure, psi
$\bar{P}$ = average reservoir pressure, psi

r_{eD} = dimensionless reservoir radius based on wellbore radius
k = permeability, md
k_r = relative permeability
μ = viscosity, cp
H = formation thickness, ft
A = area, ft^2
ϕ = porosity, fraction
c_t = total compressibility, psi^{-1}
t_p = production time, hr
t_{DA} = dimensionless time based on area

Subscript:

o oil
w water
g gas
T total

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